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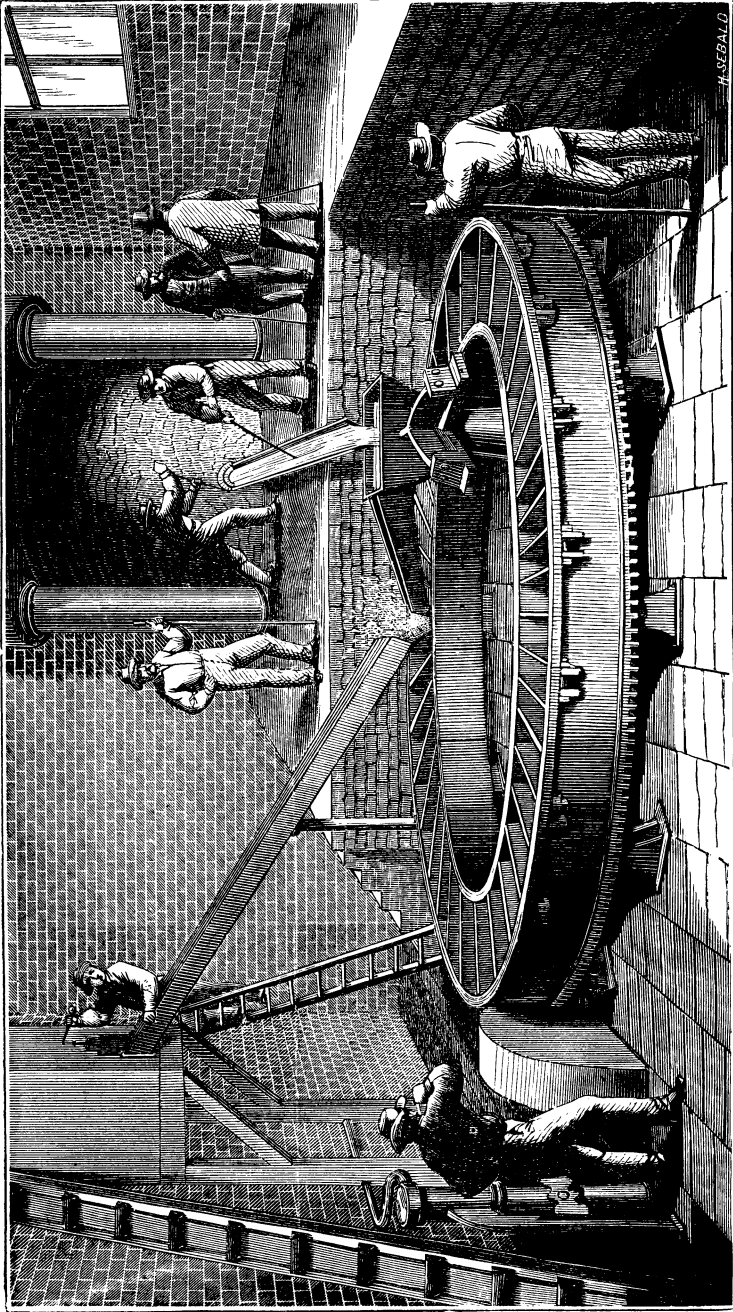
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THE ELLERSHAUSEN PROCESS, PITTSBURGH, PA.

THE
METALLURGY
OF
IRON AND STEEL,
THEORETICAL AND PRACTICAL:
IN ALL ITS BRANCHES;
WITH
SPECIAL REFERENCE TO AMERICAN MATERIALS AND PROCESSES.

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P R E F A C E .

BEFORE the author began the present work, it was thought that a simple re-editing of Mr. Overman's treatise upon Iron would be sufficient. Upon a thorough examination, however, it was found impossible to make that work meet the wants of those who would justly expect a recognition of the many important inventions and discoveries since its last edition was published, and who would not wish to read of anything as a theory which had now become a fact, or of procedures which had passed away before the advance of metallurgic science. The author has, therefore, written a work almost entirely different in method and in matter. There was, nevertheless, so much material in Mr. Overman's book which was useful, having reference both to his personal practical experience and to his advice, that it has been introduced, and acknowledged either by the use of his name or by inclosing the quoted matter in brackets.

This work treats largely upon American practice, plans, and modifications through the whole range of iron manufacture, beginning with a review of all the commercial ores used in America, and treating of American furnace-plans, methods of reduction, inventions, opinions, difficulties, and economies, from the mining of

ore and the preparation of fuel, to the formation of steel in all its varieties.

The author is under great obligation to a large number of gentlemen in various parts of this country, and to some abroad, who have aided him during the preparation of the work. Among these gentlemen particular acknowledgments are due to David Thomas, Esq., Catsauqua; C. F. Mattes, of Scranton, Pa.; Benjamin Crowther and James Park, of Park Brother & Co., Pittsburg; W. F. Foote, Port Henry, Lake Champlain; A. P. Sterling, Jefferson County, N. Y., all of large experience in the manufacture of iron in the United States. Also to Fred. Jno. Rowan, of Atlas Works, Glasgow, and to Prof. Henry, of the Smithsonian Institution, for important Foreign Reports; to Prof. G. W. Maynard, of the Polytechnic Institute, Troy, N. Y.; and, finally, to the Publisher, Henry Carey Baird, Esq., who has promptly kept the author supplied with all the important foreign works and periodicals upon the subject in hand, and whose courteous interest has been of much importance to him in the prosecution of his work.

Although the author has applied for information to many and diverse sources, his object has been to bring into prominence only that which may become practical and available in this country; and hence some processes and results characteristic of peculiar conditions and of peculiar ores and fuels, and which could be considered of great importance only under peculiar foreign surroundings, have been but briefly noticed. The an-

thracite, as well as the bituminous, practice has been particularly treated upon in all its bearings, both as regards cast and malleable iron; also in respect to the fuel itself. In Chap. III., upon the Special Properties of Iron, the author has been greatly indebted to Percy's work on the same subject. It will be seen that the general and successful furnace practice in our country does not agree with many of the theories, formulas and suggestions of European works. Our ores greatly differ, our fuels and our limestones vary, and the consequence is, that the exactness of rule and practice which is applicable to the spathic and other peculiar ores of the Continent, or to the ores of Great Britain, does not hold good with us. The same may be said in view of the large anthracite interests so peculiar to this nation; the practice most successful with us will not always be either improved or explained by conditions existing upon the Continent or in Great Britain. Hence we may expect to find that some successful practice, illustrated in this volume, does not agree with European formulas as seen in Dr. Percy's work, in Petitgand and Ronna's excellent notes, or as suggested by various other foreign publications. After repeated examinations of British and Continental Works, and after much study of foreign practice, we are confident that, notwithstanding the acknowledged scientific skill and mechanical excellence of foreign metallurgists, much of great practical importance is to be learned from examination and study of the material and the works which we have at home.

Although the author's distance from the printing office, and the urgent duties of his profession, have been the occasion of some errors, it is believed that none alter, materially, the meaning intended to be conveyed.

The author has endeavored so to prepare this work that any one with a good English education, can begin, continue, and complete the reading with a full understanding of the subject. The strictly scientific reader, or student, will therefore not be surprised to find many terms explained and many processes, especially in the theoretical part, simplified and made introductory to the more exact and perfect processes toward the close of the work, and even in the Appendix.

A very complete index, for which the work is indebted to the publisher, has been added. By its aid it is believed that every item of importance in the book can readily be found.

LAFAYETTE COLLEGE, EASTON, PA.

Aug. 10, 1869.

CONTENTS.

PART I.

THEORETIC METALLURGY OF IRON.

CHAPTER I.

GENERAL PRINCIPLES OF THE CHEMISTRY OF IRON.

	PAGE
Oxygen	18
Carbon	20
Hydrogen	20
Nitrogen	21
Ides and Acids	21
Sulphur	22
Phosphorus	23
Manganese	27
Chromium	28

CHAPTER II.

THE ORES OF IRON.

Commercial Ores of Iron	30
Magnetic Oxide of Iron	31
Magnetic Ore or Magnetite	31
1. Magnetic Mines and Ores	33
Titanic Iron Sand	38
Chrome Iron Sand	38
Geology	38
Franklinite	38
Geology	39
2. Red Hematite, Red Ore, Red Oxide, Anhydrous Sesquioxide of Iron, Specular Iron Ore	39
Geology	40

	PAGE
3. Brown Hematite, Brown Iron Ore, Hydrated Sesquioxide of Iron	43
Geology	44
Brown Hematite localities in the United States	44
4. Spathic Ore and Spathic Carbonate, Sparry Iron Ore, Sphærosiderite, Chalybite, Crystallized Carbonate of Protoxide of Iron	47
Geology	47
5. Fossil Ores	48
Geology	49
Table of Analyses	49
6. Argillaceous Iron Ores, Clay or Clay-band Iron Stones, Black-band, Earthy Carbonates	50
Geology	50
Black-band	51
Table of Analyses of Scotch Bands	53
Earthy Carbonate Ores and Calcareous Carbonate Ores, Impure Earthy Limestone Ores	54
Earthy Carbonates or Calcareous Carbonates	54
7. Bog Ores	56
Table of Analyses	56
8. Peculiar Ores	56
Review and Practical Remarks	58
Mining of Iron Ore	62
Instruments or Tools for Mining	65
Exploring	67
Sinking a Shaft	68
Timbering a Drift	73
Ground-plan of the Interior of a Mine	78
Drifting of Ore	79

CHAPTER III.

SPECIAL PROPERTIES OF IRON AND ITS COMPOUNDS.

Crystalline System	83
Magnetism	83
Tenacity	84
Specific Heat	84
Dilatation by Heat	84
Action of Heat-welding	84

CONTENTS.

ix

	PAGE
Crystalline and Fibrous Iron	85
Chemical Properties and Special Effects of Combinations as	
Alloys	89
Iron and Oxygen	89
Protoxide of Iron	90
Sesquioxide of Iron, Anhydrous	90
Appearance under Blowpipe	92
Hydrated Sesquioxide of Iron	92
Sesquioxide of Iron and Lime	93
Magnetic Oxide of Iron	94
Iron-scale or Hammer-slag	94
Ferric Acid	95
Iron and Water	95
Iron and Sulphur	96
Protosulphide of Iron	97
Sesquisulphide of Iron	100
Sulphides of Iron Roasted in the Air	103
The Protosulphide	103
Bisulphide	103
Iron and Nitrogen	104
Iron and Phosphorus	104
Manganese and Phosphorus	106
Iron and Arsenic	107
Case Hardening Iron, or Steel by Arsenic	109
Silicon	109
Reduction of Silica by Carbon, in the Presence of Oxide of Iron	
and other Bases	109
Protoxide of Iron and Silica	111
Silicate of Protoxide of Iron reduced by Carbon	111
Tribasic Silicate	111
Iron and Carbon	112
Amount of Carbon in Iron	115
Experiments of Sefström	116
Modes of Existence of Carbon in Iron	117
The Chemical Combinations of Carbon	119
Action of Sulphur upon Iron containing Carbon	120
On the Action of Phosphorus on Iron containing Carbon and	
Sulphur	121
Spiegeleisen heated with Silica	122

	PAGE
Abstraction of Silicon from Cast Iron by fusion in the Sesquioxide of Iron alone, and with the addition of Manganese	122
Carbonate of the Protoxide of Iron	122
Action of Sulphuric Acid or Hydrochloric Acid on Cast Irons	123
White Cast Iron	123
Gray Cast Iron	123
Action of Sea-water on Iron	123
Alloys of Iron	124
With Copper	124
With Zinc	126
With Copper and Zinc	126
With Tin	126
With Titanium	127
Method of determining Titanic Acid in Iron	128
With Lead	128
With Antimony	128
With Nickel	128
With Silver	128
With Gold	129
With Platinum	129
With Rhodium	129
With Palladium	129
With Aluminum	129
With Chromium	130
With Tungsten	133
With Potassium	133
With Calcium	133
With Magnesium	134
With Vanadium	134

CHAPTER IV.

THEORY OF FLUXES.

General Principles and Introductory Practice	134
Table of Proportions of Fluxes—Practical Experiments	142
Fluxes for the Blast Furnace—Practice with Fluxes—Laboratory Assays	144
Lime	144
Calcareous Spar	144
Oyster Shells	145
Analysis of Limestone	148

CONTENTS.

xi

	PAGE
Clay	151
Silex	151
Varieties of Limestone and Lime—Pure, Rich, or Fat Lime	152
Hydraulic Limes	152
Natural Cement	153
Artificial Cement	154
Puzzolanas	154
Introductory to Dry Assays of Iron Ores	155
Assays with Charcoal	156
Assays with Fluxes—Fluxes for Assaying	160
Silica	160
Glass	160
China Clay	161
Shale	161
Fire Clay	161
Good Blast Furnace Cinder	161
Borax Glass	161
Lime	162
Fluor Spar or Fluoride of Calcium	162
Cryolite	162
The Main Object of Fluxes	162
The Quantity of Ore to be Used	163
Choosing Samples	164
Proportion of Fluxes	165
Practical Directions for Assaying; Wet and Dry Methods	168
In Air Furnace	168
The Wet Assay—I. By Volumetric Assay	169
By Bichromate of Potash	169
Permanganate of Potash	170
The Wet Assay—2. By Chemical Analysis	171

CHAPTER V.

FUEL.

Remarks	178
Wood	178
Peat	182
Coal	186
Brown Coal	186
Bituminous Coal—Pit Coal	188

	PAGE
Chemical Composition	189
Practical Remarks	189
Cubical Coal	190
Slate, or Splint Coal	190
Cannel Coal	191
Glance Coal	191
Mining of Coal	191
Anthracite	198
Chemical Composition	200
Practical Remarks	200
General Remarks on Fuel	201
Table of Density of Anthracite and Anthracitous Coal	204
Table—View of the Composition of some of the Anthracite	
Coals of Pennsylvania	207
Charring of Wood	209
Charring in Heaps, Kilns	210
Charring in Mounds	214
Charring in Ovens	216
General Remarks	221
Charring of Turf or Peat	224
Charring of Brown Coal	227
Charring of Bituminous Coal, Coke	227
Coking in Rows	229
Coking in Ovens	231
Coking in Iron Retorts	238
General Remarks on Coking	238
Table of Yield of Coke from different Coals	241
Heat Liberated by Fuel	242
Analyses of Relative Value of Fuel	243
Value of Charcoal	244
Value of Peat	244
Value of Peat Charcoal	244
Value of Brown Coal	244
Value of Stone Coal	244
Value of Coke	244
Value of Anthracite	244
Table of American Coal, and the Evaporative Power of American	
Fuel	245
Practical Remarks on the Analysis of Coals	249
“Raw Coal,” or uncoked Bituminous Coal	254

PART II.

PRACTICAL METALLURGY OF IRON.

CHAPTER I.

ROASTING OF IRON ORE.

	PAGE
Magnetic Oxide of Iron	257
Hydrated Oxide of Iron, Brown Oxide, Hematite, Bog Ore .	258
Sulphurets of Iron	258
Phosphurets of Iron	258
Arseniurets of Iron	258
Chlorine	258
Sulphates of Iron	258
Carbonates	258
Roasting of Iron Ore in Ovens or Furnaces	259
Roasting in Mounds	262
Roasting in the open air in Heaps	263
Cleaning of Roasted Ores	265
Theory of Roasting Ores	267
Further Remarks in Modern Practice	268

CHAPTER II.

REVIVING, OR REDUCTION OF IRON—DIRECT PROCESS.

Malleable Iron from Magnetic Sand	275
Catalan Process	276
The Stückofen Furnace	277
Clay's Process	278
Chenot's Process	278
Yates' Process	280
Champlain Catalan Process	283
The Ellershausen Process	283
Process at Ringgold, Pennsylvania	286

CHAPTER III.

THE INDIRECT EXTRACTION OF IRON, AS CAST IRON, FROM THE ORES.

Stück or Wulf's Oven—Salamander Furnace	291
Blue Oven—Cast Oven	293
Later Forms of Furnaces	295

	PAGE
The Modern Charcoal Blast Furnace	303
Coke Furnaces	306
Hyanges Furnaces	308
Stonecoal Furnaces—Anthracite Furnaces	310
Which form is the best for a Blast Furnace?	315
Blast Furnace No. 2, Scranton, Pa., April, 1868	320
No. 5 Furnace, Glendon, one mile above Easton, Pa., 1868	323
Stack No. 2, Lehigh Crane Iron Works, Catasauqua, Pa.	326
Stack No. 4, Lehigh Crane Iron Works, Catasauqua, Pa.	326
Section of Stack No. 1, Carbon Iron Co., Parryville, Pa.	326
Section of Stack Lock Ridge Iron Co., Alburtis Station, Pa., (1868)	326
“Ringwall” or inner section and other sections of Boiler Iron and Iron Column Furnace, at Saucon Iron Works, Heller- town, Pa.	326
Forms of Furnaces at Scranton, Pa., 1856, 1858, 1862, 1868	328
Dowlais Furnaces—latest forms	334
Remarks upon the construction of Furnaces in general	335
High Furnaces	337
Lurmann’s Improvement	343

CHAPTER IV.

BUILDING, BLOWING IN, PRACTICAL REMARKS UPON THE
MANAGEMENT.

The Building of a Blast Furnace	347
Blowing in a Furnace	360
Practical Remarks	362
The Management of Blast Furnaces	373

CHAPTER V.

THEORY OF THE BLAST FURNACE.

Table showing the probable consumption of Charcoal per 100 parts of Crude Iron, with Ores of different sorts	425
Table of Analyses of Furnace Cinder	431

CHAPTER VI.

PRACTICE OF CHARGES, MIXING OF ORES, CINDERS.

Tables of Analyses of Slags	452
Slag from Anthracite Blast Furnace	454

	PAGE
Lackawanna Iron & Coal Co., Scranton, Pa., Table of Result of Blast Furnaces for the weeks ending February 15th, 1862, and March 9th, 1867	458
Charges, etc., for Fossil Ores	467
Tables of Working of Furnaces of Bloomsburg Iron Co., Blooms- burg, Pa.	467
Table of Working of Furnace of McKelvy & Neal, Bloomsburg, Pa.	469
Report of the Pennsylvania Iron Works, Danville, Pa., week ending June 20th, 1868—Blast Furnaces	471
Charges, etc., for Red Hematite	471
Magnetic Sands	474
Titaniferous Ores in the Blast Furnace	474
Physical condition of Slags	475
Practical Remarks on Charges	478
Unusual Furnace Deposits	484
Titanium	485
Various Crystalline Forms of Slags	485
Peles Hair	486

CHAPTER VII.

HOT BLAST OVENS—WASTE HEAT.

Theory of Hot Blast	494
History of the Hot Blast and of Modern Applications and Im- provements	501
The Apparatus	502
Hot Blast, Scranton, Pa.	504
Hot Blast, Saucon Works, Pa.	507
Wasseraufingen Hot Blast, Westphalia, Germany	508
"Cone and Cup" Hot Blast, Port Henry, Lake Champlain, N.Y.	511
Cochrane's Distributor, Ormsby, England, used at Port Henry, N. Y.	512
Prenat's Covering and Charge Distributor, Givors, France	513
Escalle's Method	514
Player's Blast-Oven	516
Pyrometers	521

CHAPTER VIII.

NATURE OF THE GASES AND THEIR ECONOMIES.

CHAPTER IX.

FIRE-BRICK, REFRACTORY STONES, AND MATERIAL.

	PAGE
I. Native Refractory Stones	534
II. Artificial Refractory Stones	535
Composition of Bricks	542

CHAPTER X.

BLAST MACHINES.

I. Wooden Bellows, of the Common Form	543
II. Wooden Cylinder Bellows	544
III. Iron Cylinder Blast Machines	548
IV. General Remarks on Cylinder Blast Machines	551
V. Various forms of Blast Machines	555
VI. Fan-Blast Machines	559

PRESENT FORM OF BLOWERS.

1. Fan Blowers	562
M. Alden's Blower, Philadelphia	562
F. P. Dimpfel's Blower, Philadelphia	563
Farmer's Blower, New York	563
Sturtevant's Blower, Boston	563
Applications of these Fans	565
2. Pressure Blowers	567
Mackenzie's Eccentric Blower, New York	567
Fritz & Moore Blower, Philadelphia	570
Earle's Patent Horizontal and Upright Air-Pump, South Norwalk, Conn.	570
Horizontal Blast Engine—Thomas & Laurens	573
Vertical Blast Engine, Reschitza, Austria	576

CHAPTER XI.

RECEIVERS, OR REGULATORS OF BLAST TUYERES, VALVES, &c.

Blast Pipes	581
Tuyeres	585
Valves	594
Manometer	595
General Remarks on Blast Machines, &c.	597
Player's Tuyere	599

CHAPTER XII.

HOISTS, GENERAL EXPENSES, MISCELLANEOUS DETAILS.

	PAGE
1. Hoists on Inclined Planes	601
2. Water Hoists	601
Armstrong's Hydraulic Hoists	601
Air Hoist, Saucon Works, Pa.	602
Air Engine Hoist	605
Steam Hoist	605
Economies of Furnace Practice	605
Methods in Erection	605
Positions of Furnaces	608
Scaffolding and Dropping	608
Causes and Occasions	610
Stopping the Blast	610
Cost of Erecting Furnaces	615
Cost of Furnace erected by Mr. Ed. N. K. Talcott at Dover, N. J., 1869	615
Calculations upon the Sizes of Furnaces and Blasts	620
Lindauer's Formula	621
Effect of Moist Atmosphere	631
Unaccountable Difficulties	633

PART III.

CHAPTER I.

MANUFACTURE OF MALLEABLE IRON.

I. Persian Mode of making Iron	637
II. Catalan Forge	639
III. German Forge	643
IV. Finery Fire	652
V. Puddling Furnaces	656

CHAPTER II.

RECENT IMPROVEMENTS IN THE CONSTRUCTION OF PUDDLING FURNACES

—PRESENT PROCESSES AND METHODS OF REFINING.

The Utilization of the Waste Gases	681
Double Puddling Furnaces	682
Protection of the sides of the Furnace	682

	PAGE
Protecting Puddling Furnaces with Water	682
The Horizontal Area of Chimney Flue	683
Dampers to the Flue Stacks	683
Cast Iron Bottoms	683
The Mechanical Processes in Puddling	684
Puddling for Blast Furnaces	689
Puddling with Steam	689
Methods of Refining	690
Consumption of Blast	692
Refining by Mixture	692
Incorporation of other Iron	693

CHAPTER III.

PRACTICAL REMARKS ON CHARCOAL FORGES, PUDDLING AND REFINING.

General Remarks on Puddling	695
General Remarks on Refining	719
Theory of Refining and Puddling	722
Special Process for Blooming Pig Iron	751

CHAPTER IV.

FORGING AND ROLLING.

Forge Hammers	753
Squeezers	761
Roughing Rollers	765
Merchant Rolling Mill	776
Heavy Bar and Railroad Iron Rollers	782
Sheet Iron	791
Russia Sheeting	798
Later Improvements in Hammers and Rolls	801
David Joy's Hammer	801
Dudgeon's Steam Hammer	804
Kinsey's Improvement	806
Compressed Air Hammers	806
The Gunpowder Hammer	807
Shingling by Compression	808
General Review and Practical Remarks upon Shingling	813
Improvements and Further Remarks on Rolls and Rolling	815
Wagner's Universal Rolling Mill	816
Wrought-Iron Screws for Housings	820

CONTENTS.

xix

	PAGE
Mending Cast-Iron Rolls	821
Cold Rolling	821
Grooved Chill Rolls	822
Puddling-Ball Rolls,	823

CHAPTER V.

REHEATING FURNACES, SHEARING, PILING, &c.

Reheating Furnaces	824
Heating Ovens	829
Shearing	832
Cold Shearing	836
Piling	837
Form of Keeping Accounts, &c., of Rolling Mill	839
Cost of making Rails, Cambria Iron Works, Johnstown, Pa., October, 1866	840
Cost of making Rails, Cleveland District, England, October, 1866	841
Tools	842
General Remarks	843
Siemens' Regenerative Gas Furnace	855
The Ellershausen Process	860
Johnson's Furnace	868

PART IV.

STEEL.

Introduction	870
Carbon Steel	871
Steel by Direct Process from the Ores	871
Carbon Steel by Indirect Process :—from Bar or Malleable Iron; Steel of Cementation, Bar or Blistered Steel	873
Sheffield Furnace	873
Shear Steel	878
Cast Steel	879
Indian Steel, or Wootz	880
On the Indian Method of Working Iron and Steel for the Da- mascus Gun Barrels and Sword Blades	883
On the Damascus Gun Barrels	883
Damascus Sword Blades	884

	PAGE
The Hardening Composition	884
Steel from Malleable Iron, Melted. Mushet's Steel	885
American Uses of this Metal	887
Tensile Strength of Cast-Steel Boiler Plates	891
Steel from Cast Iron, Melted	893
I. Fining with Charcoal	893
II. Puddling	893
III. Decarbonization by Forced Air and Vapor	898
Martien's Process	898
Bessemer's Process	898
Spiegeleisen for this Process	906
Bessemer Steel in Sweden	906
Bessemer Process in Neuberg	907
Heaton's Cast-Steel Process	911
Chrome Iron Steel	913
Table of Experiments made at West Point Foundry	914
Tenacity of Wrought Iron and Steel	915
Effects of Reheating and Rolling	915
Steel and Steely Iron	915
Mushet's Steel	915
Remarks upon the Bessemer Metal	916
Rolling Steel Rails	917
Steel Capped Rails	919
Weldless Steel Tyres	921
Trial of Rails	923
Analysis of Steel	924
 APPENDIX	 929
 INDEX	 943
 ERRATA	 972

THE
METALLURGY OF IRON.

PART I.

THEORETIC METALLURGY OF IRON.

CHAPTER I.

GENERAL PRINCIPLES OF THE CHEMISTRY OF IRON.

THERE is no science so largely tributary to success in Iron Metallurgy as chemistry. It is true that, of the large number of intelligent and successful iron-masters, very few have had either the advantages or the time to become chemists. But many have, in their earlier efforts, attempted impossible or useless experiments, and, before their final success, suffered great losses of material, time, and money; others have entirely failed to comprehend where "their great strength lay," and their future success; and in each case these evils have followed upon a lack of the knowledge of plain chemical truths and principles, *combined* with deficiency in mechanical and practical ability.

As it will be impossible to proceed in the present work without alluding to certain chemical principles with which the iron-master should become acquainted, we propose, at the outset, to introduce some important chemical elements and facts, with which the iron metallurgist, though no chemist, may easily become thoroughly conversant.

I. OXYGEN.—The air we breathe contains a large amount of (1) oxygen,* which plays an important part in the affairs of iron manufacture. It contains a large proportion of (2) nitrogen,† with which, as metallurgists, we have but little to do, even supposing that steel contains a small amount—into which supposition we may hereafter inquire. It contains a very small portion of (3) carbonic acid gas,‡ a compound of carbon and oxygen, the former of which two elements, also, plays an influential part, determining by its amount, as carbon in iron, whether that iron be cast iron or steel, and, by its absence from iron, that the metal in question is neither cast iron nor steel, but malleable iron.

Another fact: the atmosphere always contains more or less vapor of water.§ This water is composed of a large proportion of oxygen, and also a proportion, equal to twice the volume of this last-mentioned element, of another element and gas, (4) hydrogen. The latter element is soon to become better known to the metallurgical world, but it is the oxygen of the vapor of water to which our attention is now called particularly. Here

* By volume, 21 parts in 100; by weight, 23 parts in 100.

† The complements of the numbers for oxygen indicate the amount.

‡ Four volumes to 10,000 of air.

§ Aqueous vapor is contained in the air in quantities varying in different localities and at different times, and depending mainly upon the temperature of the air. Air, at a given temperature, cannot contain more than a certain quantity of moisture in solution, and when it has taken up this maximum quantity, it is said to be saturated with aqueous vapor.

One cubic metre of air, saturated with moisture at 25°C ., contains 22.5 grammes of water, and if the temperature of this air be reduced to 0°C ., it will then be capable of retaining only 5.4 grammes of water vapor; hence 17.1 grammes of water will be deposited as rain. The air in England is often saturated with moisture, whilst the driest air observed on the coast of the Red Sea during a simoom contained only one-fifteenth of the saturating quantity. Instruments for ascertaining the degree of moisture or humidity of the air are termed hygrometers.

In general, the air contains from 50 to 70 per cent. of the quantity necessary to saturate it. If the quantity be not within these limits, the air is either unpleasantly dry or moist.

are *four elements*, important in the following order: OXYGEN, which is the supporter of all combustion, whether as flame or burning coal, and, like that which it supports, a splendid servant, but a labor-exacting master, ever waiting and watching, in its elementary loneliness, to unite with that for which it has affinity, either to help or perplex. Its union with iron forms that which we call the "rust" of iron, in which we see this affinity accomplished, for it has recalled the metal back to its primal state, namely, that of an ore, from which ore, or rust, it was made to become a metal only by the stronger affinity of the same element oxygen for carbon, whereby the act of rusting the carbon was followed by heat enough to expel oxygen from the iron rust in the ore, and leave the metal pure. That rust of carbon is the carbonic acid gas of the chemist. However rapidly in the one case, or slowly in the other, this affinity of oxygen may be exhibited, it is an affinity always in entire subjection to a stronger law of proportion, which it never violates, whether in the long-continued processes of nature, or the more intense and rapid fires and reduction of the furnace. That stronger law is seen in this: oxygen unites with iron in the proportion of only one atom of oxygen to one of iron; or, where a stronger cause exists, and larger affinity is exhibited, it is (never otherwise than as) one and the half of one atom of oxygen to one atom of iron (Ferric Acid excepted, p. 24). Now, for the sake of brevity, the one-to-one proportion is called the one-oxide, or protoxide, and the other the one-and-a-half oxide; or, using the convenient Latin term, sesquioxide.*

Thus we have only two rusts, or oxides of iron, the protoxide and the sesquioxide. The latter is the highest affinity oxygen ever exhibits for *iron*, whatever higher affinities it may exhibit for other substances or elements. This oxide, therefore, may also be called the "high-oxide," or, again resorting to the convenient Latin syllable "per," the peroxide of iron; so that the sesqui-

* Sesqui is the Latin for *one and a half*.

oxide of iron, in this particular case of iron, is the peroxide, as there is no greater affinity of oxygen for iron known.

In the case of CARBON, however, we know of an affinity of one atom of oxygen to one of carbon; and again two atoms of oxygen to one of carbon. The former is always known as the oxide of carbon, or *carbonic oxide*, and the latter, inasmuch as the gas partakes of such acid properties that it will readily redden litmus paper (the chemist's test for acids) is called CARBONIC ACID, or CARBONIC ACID GAS. Carbon is consumable, and oxygen, as we have said, supports combustion; all the conditions, therefore, of flame or fire, exist in carbonic oxide, and it is not remarkable that it is inflammable, and that the combustion should be attended by great heat. But an anomaly does present itself in the case of the other oxide of carbon, wherein the oxygen exists as the *peroxide*, or two-oxide state. We can and need only state this anomaly, namely, that where two parts of oxygen with one of carbon exist, combustion no longer exhibits itself, nor will the gas of this composition allow any combustion to take place wherever its presence exists to any great degree. When, however, from any stronger attraction or affinity, one atom of oxygen is drawn off from the two which go to form carbonic acid gas, and the resultant gas becomes possessed of only half as much oxygen as it previously possessed, the gas immediately becomes inflammable, and burns with great heat. Singular as it may seem, the addition of two atoms of the flame-supporting element, oxygen, to one of the combustible element carbon, produces a gas which ceases to burn, nor can any combustion take place where its presence is abundant.

The element HYDROGEN commands but little attention at present, though destined to be of greater importance because of its strong affinity for sulphur, so frequently associated with ores, and exerting such deleterious effects upon the metal derived from such ores. But it is necessary to the iron-master to know, that, as water is com-

posed entirely of hydrogen and oxygen, the abstraction of oxygen always lets off the other element hydrogen, and in a state of great purity. Whatever property, therefore, hydrogen may possess, may be exhibited upon the decomposition of water. Any substance possessing a stronger affinity for oxygen than is possessed by hydrogen, will draw off the oxygen, and leave the hydrogen free. Rust is a peroxide of iron. No rust takes place which does not, in the process of its own formation, occasion a liberation of hydrogen. Water escaping from any leaking pipe or casting, and passing into a strongly heated furnace, becomes resolved not only into vapor or steam, but frequently into its elements hydrogen and oxygen, under conditions of admixture, the hydrogen with the oxygen, the combustible with the powerful supporter of combustion, so that while hydrogen, commingled in certain proportions with the common atmosphere and inflamed, would explode, hydrogen commingled with oxygen, under the same circumstances, would explode with far greater force. We have known of entire fronts of furnaces blown out by the leaking of the tuyeres of a furnace, or by ignorance and carelessness as to the effects of the sudden admission of water where decomposition suddenly took place.

OF NITROGEN, we shall say in this place only that the effects are negative. It acts as a controlling agency in the atmosphere, where it has been so proportioned by a wiser pharmacy than human chemistry can invent, that the fire-supporting element, oxygen, is completely under the control of the metallurgist. The probable presence of this element in steel will be noticed under the treatment of steel.

Ides and Acids.

Besides the affinity which carbon exhibits for oxygen, there is an affinity existing between carbon and iron. Carbon is an element with which we shall become more

specially acquainted hereafter. But it is necessary to know that it exists in three peculiar conditions: (1) *colorless crystallized carbon*, as in the diamond; (2) *black crystallized carbon*, as in graphite or plumbago, which crystallizes in six-sided plates; and (3) carbon with no definite shape (amorphous), as in charcoal, and all other coals, lamp-black, soot, etc. With the latter two conditions of carbon we have much to do.

There is a singular affinity between carbon and iron. Plumbago (called also black lead from its appearance, although it contains no lead), usually contains a small per cent. of iron, from one to ten per cent.—otherwise it is nearly pure carbon, and yet it is, as in the case of the diamond, difficult to consume. It is not a chemical combination of carbon and iron, but it is iron mechanically combined in an exceedingly minute and divided state, with a large amount of carbon in that condition known as the graphite condition.*

This condition of carbon has been called by some the metallic condition—it has the metallic appearance or lustre, and has a singular attractive affinity for iron, for while, so far as we are enabled to discover, it is not necessary that graphite should be accompanied by any iron whatever, it is seldom found entirely pure from iron present in the above mentioned mechanically divided state. It is in this form we shall meet with it in iron slags—in cast iron and in the bottom of furnaces after having been blown out, and in which state we shall speak of it as graphitic carbon.

Carbon when chemically combined with iron, forms a compound known as a CARBIDE. The special affinities of carbon for iron will be treated of more at large hereafter.

SULPHUR combined with iron forms in various proportions the various compounds called sulphides, or, as formerly called, sulphurets. These will be treated of particularly, as the combination of sulphur with iron is of practical and special importance to the iron-master,

* Graphite is a word derived from the Greek “grapho,” I write.

and is "the *strongest chemical* body next to oxygen, and has, like it, a powerful affinity for all other elements."

PHOSPHORUS in its combination with iron follows the same law of nomenclature, and produces the PHOSPHIDES or phosphurets. These are of great importance to us in the study of iron, and will be treated hereafter definitely.

Sulphur and phosphorus are peculiarly hostile to the iron metallurgist, and deserve particular study under their favorite conditions in ores or irons wherein they never appear as pure sulphur and pure phosphorus, but under certain disguises or combinations. Sulphur has an affinity for oxygen when heated, and follows the law of proportion, but the tendency of oxygen in this case is to produce acids. *Sulphurous* acid results if only one part of sulphur combines with two parts of oxygen, and *sulphuric* acid if one part of sulphur combines with three of oxygen. The same general law holds good of phosphorus. Pure, it never occurs in ores or irons, but in combination with oxygen (as one to five) it becomes phosphoric acid. As an acid it is ready to combine with lime, soda, or other bases, and introduced into the ore or limestone, used as a flux, it combines with the iron to the great vexation of the iron manufacturer, rendering his iron brittle when cold, and hence called "cold-short iron." In the animal structure it is found largely in all the bones and in other parts of the body, hence, we may find it in all limestones and ores where animal or fossil remains exist. Even in ores not fossiliferous or bog ores, but in magnetic ores which are in the immediate region of limestones containing phosphates or phosphoric acid in combination, there seems to be such an affinity of iron for this element in its combinations, that the iron ore becomes contaminated with phosphorus. This occurs among the very fine magnetic ores of Lake Champlain. Where beds of phosphate of lime have been opened, or where the rock contained phosphate of lime, the adjoining ore beds frequently contain more or less phosphate of lime, producing ores tending to cold-shortness in the iron made therefrom.

All acids with which the metallurgist will have to do,

excepting one,* owe their acid character to oxygen, which derives its name from the power which it possesses to produce acid.† The first influence of oxygen is to produce the oxide, or rust, but when the proportion becomes greater than one to one, the tendency is immediately toward producing the acid. Thus, even with iron; one atom of iron to one atom of oxygen produces one kind of oxide, or rust of iron; the combination of two atoms of iron to three of oxygen is still an oxide (the sesquioxide), being nearly the same proportions of iron and oxygen; but one part of iron and three of oxygen produce an acid, FERRIC ACID, which as an acid will unite with bases such as soda and potash, and thus produce an entirely new compound, ferrate of soda, or ferrate of potash, &c., which are salts or compounds of an intense purplish-red color, and not well known.‡ Although ferric acid has not yet been separated from its bases and obtained in an isolated state, other oxygen acids have been. Thus one of sulphur with two atoms of oxygen forms sulphurous acid; and sulphur one atom, with oxygen three atoms, forms sulphuric acid, each of which may be obtained in isolated states. Thus, a large number of bases when united with oxygen become acids, and in the form of acids will unite with other bases and form compound salts.

This is a point of importance to the metallurgist, for the decomposition of salts containing sulphur or phosphorus—whether that sulphur or phosphorus be in the acid form or in the compound salt form—is always attended with the liberation of the metallurgist's enemy sulphur or phosphorus, upon the principles already stated.

Another element in which we are particularly interested, and which is subjected to the same laws just alluded to, exists in quartz and flint, and is called silicon. There is no element excepting oxygen, more widely disseminated than silicon. The oxide of silicon is silica or quartz. What carbon is to charcoal, silica is to quartz

* Muriatic acid, or Hydrochloric acid.

† *Oxus*, acid; and *gemmae*, I produce.

‡ Recherches sur les acides métalliques, par M. Ed. Fremy, Ann. de Chim. et de Phys. 1844, in Percy, Iron and Steel, p. 24.

or flint. Charcoal is impure carbon, so most quartz and flint are impure silica with this exception in the comparison, that charcoal is a simple uncombined substance, and silica is the substance silicon combined with oxygen making silica. But the oxide of silicon, which is the same as silica, is an acid in having three parts of oxygen united with one part of the elementary substance silicon which, although never seen in nature and only prepared in the chemist's laboratory, is as an oxide the most widely disseminated.

All the flint, sea sand, sandstone, quartz, crystals, &c., and rocks of this nature are nothing less than silicon combined with oxygen, forming an acid capable, as all acids are, of uniting with bases. Silex (or silica, or silicic acid, which is the same material) unites with potash and soda to form glass, which is, accordingly, a silicate of potash, or of soda, as the case may be. When the simple element silicon unites with iron, the result is known as a silicide just as the same union between sulphur and iron is a sulphide, carbon and iron a carbide. When, however, the silicic acid or quartz-form of silicon unites with iron, the acid-ending *ate* is used, *silicate* of iron; the influences upon iron being different, as we shall hereafter take the opportunity of noticing. It is the affinity which silicic acid has for such bases as lime, potash, and soda, that enables the furnace master to destroy the affinity between the metal and the earthy silex in some iron ores by causing the silex in the ore to unite under heat with lime or potash and leave the metal free and pure. Silicon, though possessing some traits of a metal, is, nevertheless, not yet demonstrated to be a metal but rather a metalloid. What may in the future be proved in respect to silicon, sulphur, and carbon, we dare not attempt to foretell. Potash, soda, and lime were thought to be simple substances till 1807, when Sir Humphry Davy surprised the scientific world by proving that they were but oxides or rusts of metals potassium, sodium, and calcium. Silicic acid, in the form of pulverized flints or quartz, often combines with iron to form the silicate of iron tending toward cold-shortness in iron.

Another element is important and is much disguised in nature. Clay has for its base a metal, ALUMINUM. Pure clay is in part the oxide or rust of that metal aluminum, called alumina. Alumina was so called by Morveau, in 1760, because it was obtained from a solution of alum in precipitation by ammonia. The metal is now being brought into use extensively for purposes in which it is desirable to use a metal which is light (specific gravity 2.6) and not easily oxidized. When oxygen combines with aluminum in the proportion of aluminum two and oxygen three, we have the only oxide known. This is alumina and the basis of all the clays, whether red, yellow (colors due to iron and other impurities), or perfectly white as in porcelain clay, called kaolin, which is the purest form of clay. But no clay is simply alumina, although it owes its plastic nature to this base. The rest of the clay is silicic acid or oxide of silicon, with perhaps a little oxide of potassium, or potash, soda, or lime, with some water combined; hence, clay is chiefly a silicate of alumina. In treating of clay it is necessary to recognize these ingredients. Of course, some clays are colored by iron to reddish hues, and some green by chrome, and black by organic or other matter intermixed, but alumina is at the base of each, and silicic acid is the ruling acid.

All clayey ores must be treated as containing silex and alumina. Originally the clayey earth was called *argil*, hence the term ARGILLACEOUS, applied to all ores, sandstones, and substances containing much clay.

The chemical character of another substance—Lime—is important. The difference between lime and limestone is a practical one, and, after what has been said, will easily be understood. Lime has for its base a metal, calcium, a light straw colored metal which burns with an intensely bright light; in dry air it retains its brightness for a few days only and then becomes oxidized, and that oxide is the common unslacked lime. It has, therefore, a strong affinity for oxygen, and, as an oxide, a strong affinity for carbonic acid gas, producing a carbonate of lime. This is important to the iron metal-

lurgist to keep in mind when operating with lime in the furnace as a flux. All marbles, limestones, chalks, shells, &c., are lime combined with carbonic acid gas, which latter is driven off in the lime-kiln, and pure or unslacked lime remains until, exposed to the air or rain, it absorbs water, and becomes combined with water, in which case it is hydrated lime. It may absorb a little carbonic acid from the air and be in a small degree carbonate of lime.

Again, it is important to become acquainted with the metal MANGANESE. The same law of combination with oxygen, prevails in this metal. It combines with oxygen in five different proportions; the one-oxide or PROTOXIDE, the SESQUIOXIDE (as with iron) the PEROXIDE, which is one of the metal to two of oxygen. This proportion is not quite sufficient to make an acid, but one more atom of oxygen gives us MANGANESE acid. There is only one other proportion still higher, that of two of the metal to seven of oxygen, which gives a *permanganic* acid. There are, therefore, five combinations, three oxides and two acids. Of these, only one is of much importance, and is found in nature abundantly, that is the peroxide or black oxide, or the *pyrolusite* of the mineralogist. It is used abundantly in the formation of chlorine, when treated with muriatic acid (hydrochloric acid) for bleaching purposes and for obtaining oxygen gas, as by heating it, it parts with a portion of oxygen and is reduced to the lower oxide.

The use of a certain amount of this oxide has a beneficial effect upon iron and steel. Some of the ores of iron contain it, as we shall see hereafter, and, in this case, it occurs in the iron made therefrom either as an oxide or as an alloy of the metal manganese with iron. This will be considered hereafter.

The peroxide occurs in sandstones, in walls, and on the surface of the ground as broad black stains, and may be mistaken for vegetation, as it shoots off from narrow veins into the form of vegetation. It has been especially noticed in the finer conglomerate of the coal measures. When these sandstones (which are admirably adapted

for building) are carelessly selected they frequently contain the peroxide, and when placed in a building exposed to weather, this black oxide defaces the stones.

In addition to the above oxides, there are in some books two other oxides mentioned, both of which occur in nature, but neither of which may be considered distinct oxides, but merely the union of two already mentioned oxides, just as in magnetic iron ore, we have the union of the protoxide and the sesquioxide. So BROWN OXIDE of manganese may be considered, and probably is nothing more than just such a double union of one of metal to one of oxygen plus two to three, and hence called 3 of metal to 4 of oxygen. It has been found in fine crystals in European localities, and has been observed at Lebanon, Pa. Mineralogically it is called *hausmannite*.

The other oxide, found only in nature, and only another double combination of already mentioned oxides, is similar in appearance to black oxide, or peroxide, and is called *varvacite*. It is a combination of two equivalents of the peroxide and one of the sesquioxide united with one of water.*

Another element which we shall have occasion to allude to is CHROMIUM. This metal obeys the same laws of affinity. Two parts of the metal unite with three of oxygen, to form the sesquioxide which is the most abundant oxide in nature when it combines with iron in the ore called chrome iron ore near Baltimore, Md.; Texas, Lancaster County, Pa., and in many other localities. This oxide and metal are important, and will be spoken of particularly hereafter. One of the metal and three of oxygen give chromic acid, which, united with bases, is important in iron metallurgy for case hardening, and the alloy is of great importance as has been lately discovered in making steel.

In addition to what has been said above respecting compounds, another term, indicating an important practical chemical fact, should be clearly understood. Water combines with some oxides and other com-

* See more fully in Dana, 1868, and in "Turner's Chemistry."

pounds not only as moisture but in a chemical combination. Ice may be wet, but when exhibiting no moisture, have nevertheless the characteristic of being composed of solidified water. It may, if dipped into a bucket of water, have water in two states, mechanically attached to it and chemically existing in the lump. So oxides may be ores moist, or ores with water so chemically combined that no ordinary drying will drive off the water, although a very high amount of heat will eliminate the chemically combined water. The heat necessary to eliminate chemically combined water is an important element in the economical reduction of ores. The water chemically in ores, gives occasion for such ores to be called hydrated ores, or as some call them, hydrous; and ores of the opposite description are unhydrated, or, as some call them anhydrous ore. Pure red hematite is anhydrous, while brown hematites are hydrated ores. We should always prefer to call substances hydrous, which have attracted moisture *not chemically* combined, and those hydrated which have. But as the terms hydrous and anhydrous have become largely introduced, we shall adopt them.

For abbreviation we shall use the usual signs of Fe, for Iron (pure); O, for Oxygen; S, for Sulphur; C, for Carbon; P, for Phosphorus; H, for Hydrogen; Na, for Sodium;* and K, for Potassium. The oxides of these last two metals, or NaO, KO, are soda and potash, or (as the letter "a" terminal indicates an alkali) potassa. So, also, as we have said that certain higher oxides become acids, we indicate the acids by representing their exact composition, or FORMULA, to the eye by letters thus: SO^3 =Sulphuric Acid; SO^2 =Sulphurous Acid; FeS =Sulphur and Iron, making one of the Sulphides; CO =Carbonic Oxide; CO^2 =Carbonic Acid Gas; N =Nitrogen; and NO^5 =Nitric Acid; HO =Water, as these are the elements of water; PO^5 =Phosphoric Acid; Si =Silicon, and SiO^3 =Silicic Acid, or the only oxide of Silicon we know;

* Natrium being the Latin for Sodium, and Kalium the ancient name for Potash.

Mn=Manganese; MnO^2 =Peroxide or Black Oxide; MnO^3 =Manganic Acid. Thus $\text{Fe}^2\text{O}^3 + \text{HO}$, is hydrated sesquioxide of iron, and if the exact amount of water is to be expressed in the normal or pure specimen, we will use the formula $2\text{Fe}^2\text{O}^3 + 3\text{HO}$, *i. e.*, 2 equivalents of peroxide of iron to 3 equivalents of water, or in actual weight in 100 parts, 85.6 peroxide and 14.4 parts water.

The above brief notice of some of the elements involved very intimately in the study of iron, and reference to the chemical principles upon which they combine with iron, will be sufficient, at the present, to introduce the student to additional facts of which we shall treat hereafter, and to suggest upon what course a further study of these facts and elements would be advisable.

CHAPTER II.

THE ORES OF IRON.

A MASTER'S knowledge of the manufacture of iron demands a thorough acquaintance with the ores of iron. This requires, primarily, a knowledge of the chemical characteristics of each of all the commercial ores, by which we mean all those ores used in the manufacture of iron.

We propose to enumerate all the commercial ores of iron, and at the same time treat of those elements which influence favorably or unfavorably the production of iron in the furnace.

Commercial Ores of Iron.

Of the useful metals, iron is the most extensively disseminated. It may be found in the soils, rocks, waters of springs and the ocean, in vegetables and animals. The quantity of iron distributed throughout the world is incalculable. Notwithstanding some seeming contra-

dictions to the statement, it is doubtful whether iron has ever been found native, except in meteorolites, or as resulting from meteoric deposits, and then it is always associated more or less with other metals. Nevertheless, some small quantities have been supposed to be found native and pure. For manufacturing purposes, however, the metal is derived only from those ores which contain over sixteen per cent. iron. All ores yielding under that amount are considered more in the nature of fluxes than of ores, at least under the present prevalence of richer ores.

Ores contain the metal, as we have previously said, in the oxidized state, as MAGNETIC OXIDE, red hematite or ANHYDROUS SESQUIOXIDE, brown hematite or HYDROUS SESQUIOXIDE, and SPARRY ORE or spathic ore, or CARBONATE of the PROTOXIDE with particular associations and in various degrees of purity. These ores appear widely distributed, one or more in nearly every geological formation, in *veins*, *masses*, and *beds*. The *beds* of iron ore are chiefly found in sedimentary rocks, while the *veins* and *masses* are deposited in the older rocks and the oldest of the accepted geologic system. Some deposits are immense, even forming mountains, as in Gellivera Mountain, Sweden, and in the Iron Mountain of Missouri, in the island of Elba, and in the lately discovered iron regions of Lake Superior.

The most valuable ore in this country is

Magnetic Oxide of Iron, Magnetic Ore, or Magnetite.

Composition, when pure, FeO , Fe_2O_3 . Specific gravity 5.2. It contains 72.41 per cent. iron. It occurs crystallized in cubes, and in octohedrons, or in altered forms derived from the same system.

"MAGNETIC ORE," is an arbitrary name for the ore, suggested because it always influences the magnetic needle, and may sometimes be found possessed of polarity sufficiently developed to cause the ore itself to attract fragments of its own mass, or pieces of iron, as nails, tacks, &c., if brought sufficiently near to it.

It is always dark-colored, and when purest, black, frequently appearing in aggregated fine particles, from the size of fine sand-grains through all intermediate sizes to that of large peas and even hazelnuts. The faces or sides of these grains are often splendid, and the grains are sometimes, erroneously, called crystals. They do, in some cases, appear very much like crystals which have been distorted by pressure, but they have no regular form, being only uniform in their irregularity.

The most perfect ores of the *large granular structure*, occur along the mountain lines skirting Lake Champlain on the west, and are generally known as "Champlain Ores," where they are found in greater quantities than in any other section, new mines having been opened within only a few months. It is this ore which is used extensively for "lining" (as it is technically called) the sides and cracks in puddling-furnaces, the granular structure causing it to crumble under the hammer into sizes readily placed along the hearth or floor, or upon the sides, where it soon becomes soft or pasty as it melts and combines with the slag of the furnace, and thus stops up cracks and crevices which otherwise would cause waste of iron.

Ores of similar structure occur in Morris County, New Jersey, in several mines, but by no means in so large quantities, and, beside, the impurities do not allow of their being used so freely for puddling purposes.

This ore also occurs in the same regions in masses unbroken by grain or fissure, also with silica interspersed among the grains or pervading the mass in veins, thus reducing not only the per cent., but rendering it necessary that the limestone flux should be increased, and that the "charges" or proportion of limestone, ore and coal should materially differ from those charges used with pure ore.

In all these variations, however, the powder, or, as it is called, the "streak" is black, or nearly black, and sometimes, though rarely, gray.

1. *Magnetic Mines and Ores.*

New York.—Sterling Mines, Warwick township, Orange County. There are many veins in and about this region.

Clifton Mines, twenty-four miles from Fullersville, St. Lawrence County.

“Jayville Bed,” about fifteen miles east of Antwerp, Jefferson County.

A few miles east and west of Greenwood Station, Orange County, New York, on the New York and Erie Railroad.

The chief deposit of what is generally considered the purest magnetic ore, is in the region immediately upon the west shore of Lake Champlain. After a visit to that region last summer (1868), and a careful examination of the ores which are now being opened in new localities, we are convinced that there are in some of the beds no less than three kinds of ore, differing in appearance and in the effects which they produce upon the quality of the iron manufactured. Each of these three kinds may be taken from the same shaft, or so-called “bed.” From the old Cheever mine, the ore is generally considered the best. It is brought to the furnace at Port Henry (W. T. Foote, Superintendent) in masses composed of large pea-sized grains, having lustrous cleavage faces, or crystalline facets, easily disintegrated, and used, as we have said, extensively at the various puddling furnaces throughout the country for stopping cracks and holes, which it readily does by becoming, with the slag, pasty. This is apparently a clear magnetite. But from the same mine, and thrown into the same heap, we have selected masses of different grain, and largely interspersed with almost transparent, slightly colored, smaller grains of silex, so uniformly disseminated, and in such quantities, that it seemed almost impossible under the treatment of the former kind to produce with this any other than a mottled or “high” iron, having a strong tendency to cold shortness, from no other cause than silica not properly fluxed, although we failed to dis-

cover any traces of phosphoric acid in any shape. When a large quantity of this latter kind of Champlain ore is used in the puddling furnace, it is plainly desirable to use lime to render the slag less "cold" or sluggish, and in the furnace it would require a larger proportion of limestone of a pure quality.

A few miles from this mine, and some miles from the shore, are the Moriah beds. These ores are again varied, some portion almost, if not quite, equal to the Cheever, though not so granular, and more massive and compact. Some contain decided traces of phosphoric acid; others again containing silicate of magnesia and lime under the form of sahlite and other pyroxenic gangue, being lean to the amount of at least twenty per cent. of this gangue, and in some cases having full fifty per cent. of a very black and heavy hornblendic impurity. On our way to the mines we passed some fifty tons, examining each wagon, and finding these differences of quality in every second or third wagon. These were all from the Moriah beds, and were being shipped south from Cedar Point to various places hundreds of miles distant. We were thus enabled to account for the fact, that, at various puddling furnaces in New York, Pennsylvania, and New Jersey, we found this variation of material in the same heap, and sometimes in heaps of two or three tons each.

In the same region, and nearer the lake, there has been opened a bed of phosphate of lime. This bed has been worked, but we understand not so successfully as was hoped. The irons in general proximity to these phosphate rocks are said to be all, more or less, contaminated with phosphoric acid.

From the general trend of the ores the finer ones seem to extend northward from Crown Point, in which latter region, several beds of poorer ore have been opened, and it is highly probable that large "beds" or veins of magnetic ore of an excellent quality will be opened in the ranges and along the hills farther north toward Westport township.

We have seen similar ores from Morris County, N. J., on the line of the Morris and Essex Railroad, but the quantities of such ore, from this region, are always

small. It is only by comparing them side by side that *picked specimens* can be distinguished. The great impurity of these Morris County ores is found in the sulphide of iron they contain when quantities are used. Another undesirable impurity is the large amount of siliceous matter in different forms, and sometimes in associated hornblende which the miners are not careful to distinguish, and which no doubt causes immense loss to some furnaces by expense of freight on worthless gangue, of loading and unloading, and the loss by the high irons produced, together with the wear of furnaces.

New Jersey.—Important mines are worked six to thirteen miles west of Boonton, Morris County; at Irondale, about eight miles east of Stanhope, Sussex County; Ironhill, one and a half miles west of Ringwood, Passaic County; near Wawayanda Lake, northeast of Sussex County.

Franklin, Sussex County.—Here is the noted Franklinitic ore containing zinc and manganese, and making “Spiegeleisen iron,” which contains manganese, and, some have said, as high as 20 per cent. zinc. (See under “peculiar ores.”)

Passaic County, in the northwest, is where the magnetic iron line begins in this State, and it continues southwesterly along the west line of Morris County, where it widens eastward, and continues with great probability on the limits common to Hunterdon and Warren Counties. It crosses the Delaware into Pennsylvania, and the ore is worked in the hills south of Riegelsville on the north of Bucks Co. We have found it south of the Lehigh, at the top of the Williams-township hills. In some parts the magnetic attraction is strong enough to deflect the needle. Beyond this it is broken, but appears to continue again toward Lebanon County, where it may be considered as reappearing in the Cornwall mines, but as, comparatively, extremely impure and irregular magnetite.

Oxford Furnace mines, Warren County, have been worked for many years. The ore is a grayish-black magnetic with some sulphide, but if mixed properly, not enough to be necessarily red-short. *Morris County,*

on the line of the Morris and Essex Railroad, New Jersey, is rich in ores of this class. In some beds the ores are strongly polaric as well as simply magnetic—in some places they are granular and resemble the best old Cheever ores of Lake Champlain, except that they are inclined to be sulphurous. Some are siliceous and feldspathic, and exhibit decided phosphoric elements, others, again, contain much gangue of a dark green or black character, which is always objectionable, being difficult to flux and flow, and hence, aiding to cause obstructions in the furnace, or what is known as “scaffolding.”

The chief mines of this region are the Hibernia, three miles from Rockaway; Mt. Hope, Tebo, Mt. Pleasant, and Orchard, on the Mt. Hope Railroad; Ogden mine, the Hurd, Weldon, and Ford, in the vicinity of Brooklyn Pond, accessible by the Ogden Mine Railroad. At Suckasunny the Dickerson mine, and between Suckasunny and Dover the Byram mine. All these may be reached through the Morris and Essex Railroad, and represent the New Jersey magnetic ores.

Also, in Stone Valley, northern part of *Huntingdon* Co., Pa. (See Appendix B.) In Lincoln Co., N. C., said to be a nickeliferous magnetite. In Gaston Co., North Carolina, at the High Shoals Rocks, and Allison and Morgan “Banks.” The magnetic ores which we have examined from these mines are granular, and though siliceous to a considerable degree, are open and readily worked, making a good iron with proper care. The Morgan Bank ores which we have examined, evidently show a transition condition from magnetite to red hematite, some specimens containing both magnetite and red oxide. In South Carolina, it occurs in “ore beds” along the north side of King’s Mountain, and near People’s Creek, possesses much oxide manganese, and may be a pure “steel ore,” *i. e.*, making a good iron for steel.

In Georgia, near Alatoona, there is a granular magnetite of cleaner and purer character than the last mentioned and very valuable. In Cass County, near Cassville.

Also, a few miles from southwest base of Pilot Knob and Little Iron Mountain, and as there appear to be vast quantities, there will be equally large quantities

mined at no distant day. The most splendid magnetic ores not mined, or some of the purest we have seen, are found amid the spurs and outposts of the Rocky Mountains. From Colorado, near Buckskin, some specimens we have flattened considerably under the hammer upon an anvil without breaking them; but they are massive and without any granular appearance.

The region west of Marquette, Michigan, near the north line of Appleton, and on the north side of the Menomonee River, possesses the largest masses of workable and worked ore perhaps in the country; some of it is almost absolutely pure. The ores are chiefly magnetic, although there is specular ore also. Analysis by M. Rivot, Professor in Paris School of Mines (*Annales des Mines*, S. 5, I. X. p. 411) present the following composition:—

Metallic iron.	Oxygen combined.	Gangue rock.	Alumina or clay.	Lime.	Water.
33.5	14.5	43.0	1.5	2.5	4.6
38.5	16.2	43.0	1.5	1.0	0.0
40.0	17.3	38.5	2.5	0.8	0.0
49.0	21.0	26.0	2.5	1.0	0.0
50.0	21.0	21.5	6.5	0.5	0.0
51.5	22.0	23.0	2.5	0.5	0.0
58.0	24.5	11.0	3.5	2.5	0.0
58.0	24.0	15.0	2.0	0.8	0.0
59.0	25.0	11.0	1.5	2.0	1.1
64.0	27.0	6.5	2.0	0.2	0.0
66.0	28.0	1.5	2.5	1.7	0.0
67.0	28.3	2.0	2.5	0.0	0.0
67.0	26.0	4.5	1.5	1.0	0.0

Extensive bodies of this ore exist also in Wisconsin, south of Lac des Anglais. Beds from twenty-five to sixty feet thick are reported. (*Owen's Rep. of Iowa*, 1852, pages 144 to 147.) Analysis of one specimen by Dr. Owen, gave perox. 51.5, protox. 27.1=78.6=56.3 per cent. iron; SiO_3 20.8; MgO , 00.6; alkali, 0.02; fluoric acid, trace. Also in Oregon (*J. R. Brown's Rep.*, 1866).

We have found in the Emery quarries at Captain Elliot's Chester factories, Connecticut, that magnetite was largely associated with emery, and the streak or powder was gray, due, perhaps, to the argillaceous

nature of the specimens. The mineral was once mistaken for iron ore, until found absolutely refractory in the highest heat of the furnace.

TITANIC IRON SAND has been dug and quantities brought to this country from Labrador. What we have seen of this sand was magnetic, and possessed a high percentage of iron, but was only introduced for the purpose of attracting attention to its merits as an ore, whatever those merits be. (See **IRON** and **TITANIUM** hereafter.)

CHROME IRON SAND in octahedral crystals may be generally though not always distinguished by its not being magnetic. This ore is the one from which the best iron for steels has been obtained.

Geology.—It is widely diffused, occurring in the so-called igneous and metamorphic rocks, *e. g.*, Gneiss, Granite, or allied rocks, in masses or layers. Isolated crystals occur in clay slate, chlorite slate, greenstone, and basalt. Wherever we find it so largely disseminated as to be worthy of mining in this country, it has been found in the rocks of the above nature.

In Europe the finest natural magnets are found in Siberia, in the Hartz, and in the island of Elba. Some natural magnets have been found in the region of Lake Champlain. We have found some specimens very strongly polaric from the mines in Morris County, New Jersey.

FRANKLINITE.—Formula still doubtful. Sp. grav. 5.1.

It was regarded as essentially a magnetic oxide, with the protoxide partially replaced by oxide of zinc. Some analyses seem to contradict this, but, till further light on the subject, it may be thus classed. Rammelsberg's analysis is—

				Dickerson in C. I. Jackson's Rep. on N. J. Zinc Mines.	
Sesquioxide of iron	64.51	= Iron . .	45.16		66.07
MnO ₂ , or binoxide of manganese	13.51	Manganese . .	9.38		12.24
Oxide of zinc	25.30	Zinc . .	20.30		21.39
		Oxygen . .	25.16	Silic	0.29
		<hr/>		<hr/>	
		103.32	100.00	99.99	

It is treated as an ore of zinc, and when the iron is

smelted it appears as a characteristic spiegeleisen.* The ore has been recommended as a remedy against both cold and red-shortness. It is supposed that sulphur and phosphorus were extracted by the zinc and manganese, or by the zinc alone, and thus were removed the chief causes of red and cold-shortness.

Geology.—In granular and rhombic limestone, of the metamorphic silurian, in Sussex County, N. J. It is said to occur massive at Altenberg, near Aix la Chapelle.

2. *Red Hematite, Red Ore, Red Oxide, Anhydrous Sesquioxide of Iron, Specular Iron Ore.*

When pure its composition is Fe_2O_3 , and it contains 70 per cent. iron, oxygen 30, sp. grav. (crystallized) 5.3 to 4.2 earthy kinds. It occurs crystallized as in specular iron ore, with black shining facets, and sometimes beautifully colored; or as micaceous iron ore, with thin, bright, and apparently black scales or fibres, according to the character and size of its crystalline grains or particles; and also in massive and reniform or botryoidal states, and even earthy. Sometimes fibrous and radiating, hard and siliceous to the touch, while some are soft and even greasy to the touch. The hardness of some varieties is due to silica in the state of quartz; and when this is the fact, without the presence of alumina, lime, or magnesia, the pig iron resulting will be rich in silicon.

It may always be distinguished in that it produces a characteristic *red streak* when drawn across unglazed porcelain, and a red powder when delicately pulverized and placed on white paper, or when scratched with a file. [The red color of the common brick is due to this oxide of iron. All the red clays belong to this class, and, when they contain more than 20 per cent. of metal, may be considered an ore of iron.]

Those varieties of specular iron ore which have lost their metallic appearance, are called red iron ore; they are either fibrous or solid, compact or ochry; sometimes

* "Looking-glass iron," from its large, bright, crystalline fracture.

they form a firmly connected mass of a red impalpable powder. The scaly red iron and the red iron foam belong to this class; in masses they are but slightly coherent.

This variety of ore yields very unequal amounts of iron; it ranges from the red clay of hardly 12 per cent. of iron, to the rich micaceous ore, which is pure oxide of iron. Therefore, the evidence of sense is no safe criterion, for a very poor clay *appears* sometimes as red as the richest ore—though by drying the specimens, a difference in color may be perceived: still, it would be premature to infer from this, what amount of iron a given specimen contains. The only way to ascertain the quantity of iron is by chemical analysis, and the humid is the only test we can certainly depend upon. But this variety of ore yields *always* good and strong iron, and is, perhaps, on that account, the most valuable; for the iron manufactured from it is the most tenacious of all kinds. It improves, even in small quantities, all inferior ores, and may be used as an excellent flux in the blast furnace. The damask iron of Persia and the woots of India are manufactured from specular iron ore.

Geology.—The massive and earthy varieties occur in the carboniferous limestones of Lancashire and Cumberland, England; in the same stone at Mumbles, near Swansea; in the Devonian limestone of Berryhead, near Brixham, it is found associated with sulphate of baryta; also at the base of the carboniferous limestone south of Liege and Huy, cropping out along many miles of country. [Specular iron ore is found throughout Asia, Corsica, Germany, France, Sweden, and in almost every country.] In the United States, in the metamorphic or transition rocks from ancient to secondary rock. The Pilot Knob is made up of quartzose rock of the azoic period. In Warren County, New Jersey, where it occurs opposite Easton, it is associated with pyroxene and hornblende (see list in Appendix A). The fossiliferous red hematite of Oneida County is in the upper silurian, and the sandstone of that formation. The Lake Superior hematite lies between chlorite slate, hornblende, and highly crystalline feldspar rocks. In Wisconsin, on the

east branch of Black River, near the falls, the red ore passes up through mica slates and chloritic slates. (*Lesley*.)

In Bohemia and the Hartz it occurs in reniform* masses of a fibrous concentric structure. As a mineral, perhaps indicative of beds or veins, where mines have not been opened, it occurs compact and micaceous, abundantly in St. Lawrence and Jefferson Counties, more fully described hereafter, under the head of worked ores or mines. Beautiful colors, or irised crystallizations, are found at Fowler, a port township of St. Lawrence County. Splendid micaceous specimens occur in the Marquette ores, Lake Superior.

These black or dark crystals, when cut thin, are translucent, showing a color of deep-blue red.

Compact red hematite is rather difficult to work, although when worked it produces pure metal, and is not so liable to impurities as the next mentioned ore, brown hematite. But there are more open varieties, which are of easy management. Although the Oneida County, New York, red hematite is put under the head of fossil ores, it is actually a red hematite, with impurities which, when properly managed, do not materially interfere with the purity of the metal produced, and the ore is fluxed with ease compared with the compact variety of pure, or nearly pure, red hematite. Though there is less iron in the next mentioned hematite, for the same weight of ore, even when both are pure, because of combined water in the ore, yet, when heated or roasted severely, that combined water leaving the ore renders it more porous and more accessible to the reducing heat of the furnace. It becomes by such heat a red hematite. This is the cause of the change of color in many instances where a yellow or brownish or even gray ore has been roasted thoroughly. Of course, economically speaking, more heat has been expended upon the brown or hydrous hematite, as all the water (ten to fourteen pounds to the hundred of ore) has to be expelled, and with its expulsion carries off so much heat unexpended upon the direct reduction of the metal.

* Kidney form.

Some of the principal mines of RED OXIDE occur as follows:—

In New York State there is mined a lenticular ore, or “fish-egg” ore, being a deposit of small shells and red oxide of iron, having its northern outcrop at about nine miles west of UTICA, Oneida County. It is said to underlie the Catskill and Alleghany Mountains, and come up at Danville and Bloomsburg, in Montour and Columbia Counties, Pennsylvania. It is also mined at Cumberland Gap and in Blair County, and lately near Rome, Georgia. This is not a usual red hematite, but fossiliferous, and hence is described under that class of ores.

PILOT KNOB, Iron County, Missouri; also, on the Maramec River; at Birmingham, on the Mississippi, 120 miles below St. Louis, and in other parts of the State. Some of the veins run nearly vertical.

Immense beds exist at JACKSON MOUNTAIN, Marquette County, Michigan. Some of the specimens from the heaps of ore are black, shining, and apparently laid down in thin layers; but are red, when seen by transmitted light, and are then called *micaceous* red hematite. Some varieties are of the mineralogical species göthite, with a crystalline radiated structure, containing, when pure, about seven per cent. water; but this last ore is rare, the micaceous frequent. Analysis gives oxygen 29.46; iron 68.07; insoluble 2.89; no manganese, phosphorus, or sulphur.

Near and around ANTWERP, Jefferson County, New York. This is a remarkable and beautiful ore, largely mined, and as interesting to the mineralogist as to the metallurgist. There are found beautiful hairy radiations of sulphide of nickel (millerite) in cavities of this ore. Some specimens presented to us by A. P. Sterling, Esq., contain the sulphide of nickel in roseate form. This ore is easily worked and very valuable. There are many openings in this region.

Forty miles northwest of MILWAUKEE there is an oölitic and siliceous variety called, geologically, an upper silurian red hematite.

East of EASTON, Pennsylvania, across the Delaware at a place called Marble Hill, there is a vein of massive

ore cropping out, which has been mined, and some ore is stacked up, but the mine has been abandoned. It is a siliceous, massive, compact ore, containing about 48 per cent. iron. The vein has been traced into Pennsylvania, northwesterly, a half mile.

There are immense quantities of this ore in Wisconsin, and they were partly worked some years ago on the east bank of Black River, near the falls, four miles from flat-boat navigation. Analysis, by Dr. C. I. Jackson, perox. iron, 67.50 (=47.25 metal); silica, 26.75; oxide mang., 3.65; water, 1.50.

3. *Brown Hematite, Brown Iron Ore, Hydrated Sesquioxide of Iron.*

$2\text{Fe}^2\text{O}^3, 3\text{HO}$.—When pure it contains 59.89 per cent. metallic iron, and 14.44 per cent. water, but the water varies much in different localities and in different conditions of the hematite. Under the term Brown Hematite Ore are included all the ores, the essential ingredient of which is hydrated sesquioxide of iron. The finely fibrous, rich dark-brown hematite is nearly pure, excepting about from .5 to 5 per cent. silica; whereas the majority of the ores of this species are ochreous, earthy, and yellow-brown, or, when from low grounds, they are in the shape of brittle and loosely aggregated masses, called bog iron ore. Dana includes all these varieties under the specific name of LIMONITE; whereas Percy, and ore men generally, call them BROWN HEMATITE. The streak powder of all these ores is brown or brownish-yellow. Those of the Belgian districts are, by Percy, supposed to yield not much more than 30 per cent. iron. Its forms are various—globular, reniform, stalactitic, and mammillary. It presents great variety of surface, being smooth, granulated, reniform, drusy, columnar; and it is often an impalpable powder. It is a species which, on account of differences in regard to mechanical composition, has received a great diversity of names; still, all the varieties are of the same chemical composition, unless adulterated by foreign matter. The whole class is the result of the decomposition of other iron compounds,

namely, iron pyrites, carbonates, red oxides, sulphates, &c. The fibrous limonite, or brown hematite, comprises sometimes beautiful forms of the hydrate, which are known under the name of pipe ore, brown ore, and shell ore; it is then reniform, and often consisting of alternate layers of different colors, or coats of different hardness. To this species belong also a great variety of impalpable and scaly combinations.

Geology.—Occurs in the secondary or more recent deposits. The earthy-brown occurs abundantly as a superficial deposit in the oölite of Northamptonshire and in Lincolnshire, England.

In the United States, the largest deposits are in the lower silurian. Some ores of this kind are mined from the outcrops of the coal measures, in western and middle Pennsylvania, and in Ohio.

The following are some of the brown hematite ore localities of our country, where they are, or have been, worked:—

New York.—Near Copake, Columbia County, and near the east side. The ore of Dutchess County seems to be a mass of ore very varied in shape and size, makes excellent iron, especially that near Dover Plains and indeed anywhere on the Salisbury Range within twenty miles. Salisbury iron is noted as an excellent iron.

Massachusetts.—Richmond and West Stockbridge mines, eight miles southwest of Pittsfield; principally in Berkshire County.

Connecticut.—Near Kent, Litchfield County; several “banks,” “mines,” “beds.”

New Jersey.—Edsall’s mine, near Hamburg. Near Stewartsville, on the Morris and Essex Railroad, a remarkably siliceous ore, splendidly brilliant, with microscopic crystals. Lately opened.

Pennsylvania.—Ironton mines, near Fogelsville, nine miles northwest of Allentown. These are very old, and perhaps the most remarkable in the country for depth, variety of color, and methods of open mining. Some time ago some exceedingly beautiful specimens of arborescent native copper were found there. The ore, which is

nodular, is remarkably pure in parts, especially at Balliot's mine, and the adjoining one under the direction of Gen. Robert McAllister. The latter is the most interesting bed for miles around, and, we think, for purity of ore is not excelled anywhere, especially when the ore is thoroughly washed. We have picked up specimens of the silicate and carbonate, but no sulphide, of copper. Kind, geologically—lower silurian brown hematite, as all is in this region. About nine or ten miles northeast of Pricetown, some ten miles northeast of Reading. Not far off, about ten miles northwest, is a true magnetic vein. (See under MAGNETIC ORE.) South of Easton, about a mile and a half in Williams Township. Beds are here extending some five miles, nearly continuous on the north side of Lehigh Hills, running east and west. Mined out by shafts; some open beds. Nodular, but not so hard as at Iron-ton, and more of the bomb ore; some hollow "bombs" half filled with water. In these beds the mineral ore *Göthite*, a fibrous, reddish-brown, radiated hematite is found; also a beautifully iridescent black-surfaced bombshell ore, very beautiful specimens of which have been taken out formerly. Above and below Albertus Station, for twelve miles east and west of that station on the line of the East Pennsylvania Railroad, running southwest from Allentown; also near the North Pennsylvania Railroad, several miles south of Bethlehem, near Coopersburg; and also at several points on either of these roads beyond. All of these beds, for many miles, seem to be but the broken continuation of the same general line of lower silurian. Brown hematite ores run from the Delaware, opposite Easton, southwesterly over one hundred miles, even into Maryland, beyond and south of York, Pennsylvania. Some of the beds southeast of York, judging from specimens we have examined, contain a large per cent. of manganese. One specimen, said by the gentleman who gathered it to be a sample taken from some seventeen tons mined out for *brown hematite*, contained more than 50 per cent. peroxide of manganese, and it could not be melted in any ordinary furnace.

It is mined with fossil ore, or in the same vicinity, in

Huntingdon County; mined also, free from fossil ore, in the north part of this county (Huntingdon), in and about Stone Valley, and west of Mifflin County, and east of Blair County. In Maryland, at Point of Rocks, forty-five miles west of Baltimore, and further southwest also, so we have been told, beds are found, and beginning to be mined in Baltimore, Carroll, and Harford Counties.

Virginia.—Ten miles west of Fredericksburg, in Loudon, Spottsylvania, Nelson, Frederick, between the Blue Ridge and Alleghany in Warren County; Page (southeast part), Rockingham and in Augusta County northwest of Staunton, and in other directions from Staunton, and more would be mined with a little more skill and enterprise in this region; so also in Rockbridge. Excellent ore in Appomattox County.

In North Carolina.—In Gaston County several beds are good at the High Shoals; one also at Mine Hill. Richards Bank: in some specimens from this “bank” we found some small particles of gold; there is a quartz gold vein in the vicinity; also in Spartanburg district. We do not know of any mines worked at present in South Carolina, but there are beds probably in the western part of the State, especially around Pendleton, where we have, for miles, picked up surface specimens. In Georgia, in the region of Cassville, Cass County. In Alabama, sixty miles north of Montgomery, and east of and along the Coosa River; and there are immense amounts of excellent ore lying on the surface not mined up to the spring of 1868, but lately purchased for that purpose. In Tennessee; in Carter, Washington, and Monroe counties.

There are soft, and what is called “hematized outcrop, coal measure, carbonate ores, in layers two feet thick,” said to be fourteen miles southeast of Butler, Butler County, Pennsylvania, and in several other places in the country around, and in neighboring counties. So also in Lawrence County, Ohio; Scioto County, and in Greenup County, Kentucky. A true ore, within one or two miles northwest of Dycusburg, Crittenden County, Kentucky, a few miles northwest of Eddysville, Caldwell

County, and also from five to eight miles south, said to be very pure and fit for steel. In Tennessee, a large quantity is found in Stewart County, and so in Montgomery County; a lesser quantity in Dickerson County; some mined in Hickman, Perry, and Decatur. Some of these ores contain a high per cent. of manganese, and make an excellent spiegeleisen, judging from personal examination of both ore and iron. In Missouri, forty-five miles west-southwest of St. Louis; also in Illinois, northwest of Elizabethtown, Harden County. In Wisconsin, some miles west of Barraboo Village.

4. *Spathic Ore and Spathic Carbonate, Sparry Iron Ore, Sphærosiderite, Chalybite, Crystallized Carbonate of Protoxide of Iron.*

FeO, CO^2 . Anhydrous, and, when pure, contains 48.275 per cent. iron, generally associated with carbonate of protoxide of manganese and carbonate of magnesia, and also lime. The color is light yellow, or light brown; streak white; when nearly white, or cream colored, it is nearly pure—as in Roxbury, Connecticut. It is then considered a fine ore for all steel-irons. The principal ancient locality in Europe is the Erzberg, near Eisenerz, in Styria; it is also found in Prussia, at the Stahlberg near Müsen; and here the iron and copper pyrites, which occur, are picked out by the hand. In England it is found in the Brendon Hills, and Exmon, Somersetshire. In this country, as we have said, at Roxbury, Connecticut, and in Plymouth, Vermont. There is a variety called “clay iron stone,” which is a siliceous or argillaceous carbonate of lime, and which we shall describe further on.

Geology.—Found in Gneiss, as in Styria and Carinthia, mica slate, clay slate. Occurs frequently with other metallic ores. The sphærosiderite form occasionally occurs in trap-rock. In Roxbury, Connecticut, it is associated with quartz traversing gneiss, and is there called “steel ore,” and mined principally for this purpose. At Sterling, Massachusetts, it occurs also pure. We have seen considerable quantities mixed with the

red ores of Sterling mines, Jefferson County, N. Y., but not enough to be mined separately. With these exceptions, this ore is not used to any considerable extent in this country, when compared with the ores already mentioned.

5. *Fossil Ores.*

The "fish egg" Clinton ore, west of Utica, Oneida County, New York, is so called from its general appearance, but it is an argillaceous red fossil ore, and is used in great quantity and sometimes called "lenticular," because of the flattened shape of its grain, though the particles, to a great degree, resemble a fossilized fish roe. It is the "Oölitic fossil ore." The ores twenty-five miles west of Kingston, Ulster County, New York, are supposed to originate from the same general bed, stretching along from Oneida County, and running under the Catskill and Alleghany Mountains, and coming up again in Montour and Columbia Counties.

In Montour and Columbia Counties, PENNSYLVANIA, where these ores are worked extensively, there are found a great many fossils of a ring shape, which are the separated stem-sections of encrinites, somewhat altered in shape, and of diameters varying from one-quarter inch to three-quarters of an inch. The upper ores, near Bloomsburg, are more calcareous, the lower are siliceous. The ores vary from a brownish-red to a brownish-chocolate color. Also, worked at Lewistown, Mifflin County, Pa., at the base of Jack's Mountain. In Bedford, in Huntingdon County, Pa. Near Dry Valley, a small village in Union County, Pa. In Centre County, where it is said to make both red and cold-short iron. Near foot of Tussey's Mountain, Huntingdon County, where is both fossil and rock ore. East part of Blair County. In Bedford County, near Tussey's Mountain.

In *Virginia*, in Shenandoah County, about ten miles southeast of Woodstock.

In *Tennessee*, in Carter County, at Cumberland Gap, in Claiborne and Union Counties, and up the Tennessee River.

Also, in Greenup County, Kentucky.

They appear in other places where they have been either worked, or opened with the intention of working. They are modified conditions of red, and sometimes, brown hematite with silica and more or less carbonate of lime, sometimes enough, from the fossil shells, not only to render limestone unnecessary as a flux, but, in some cases, to require some siliceous ore as a flux to work them, as, for instance, in Madison County, at the head of Oneida Lake, New York.

Geology.—In the Upper Silurian.

The following analyses of some of the varieties will aid in determining the nature of this class of ores.

Locality and variety.	Peroxide of iron.	Oxide manganese.	Alumina.	Silica and insoluble matter.	Water.	Occasional ingredients.	Loss.	Metallic iron in 100 lbs.	Description of the ores.
Smith's Gap, Kittatinny Mt., Dauphin Co.	68.00	....	6.60	13.30	11.70	.....	.40	49.44	Dark mottled brown, coarse grained, imbedded in br'n hematite.
Danville, Montour Co. (Levant iron sandstone.)	70.63	....	.57	23.77	2.57	Carb. of lime 2.46	....	48.95	Brick red, somewhat fossil; grain and aspect of red sandstone called "hardore."
Danville, Montour Co. (Calcareous fossil ore.)	30.34	trace	....	2.64	1.80	Carb. of lime 62.43 Carb. of magnesia, 2.79	....	21.24	Dark purplish brown, slaty, micaceous fossil.
Bloomsburg, Columbia Co. (Compact calcar. fossil ore.)	61.30	....	trace	2.80	2.20	Carb. of lime 33.17	.53	42.91	Similar to last.
Bloomsburg, Columbia Co. (Soft, porous, fossil ore.)	85.10	....	5.00	7.10	2.10	Carb. of lime trace	.40	59.57	Dark reddish-brown, soft, gives a red powder full of pits and casts of fossils.
Mifflin, Juniata Co. (Fossil ore.)	70.00	trace	trace	24.24	5.40	.....	.40	49.00	Chestnut brown coarse, slaty, granular, micaceous and fossil.
Matilda Furnace near Jack's Narrows, Huntingdon Co.	74.76	trace	5.06	13.04	3.82	Lime 1.35 undetermined matter 2.11	....	52.33	Reddish brown, powder red, porous (upper part of fossil ore).
Matilda Furnace lower part of the same.	44.07	trace	1.39	52.33	2.62	Lime 0.49	....	30.84	Brown, fracture rectangular; brown ox. of iron, cementing coarse grs. of sand (lower part of fossil ore).

6. *Argillaceous Iron Ores ; Clay or Clay-band Iron Stones, Black-band, Earthy Carbonates.*

Impure earthy carbonate of protoxide of iron.

Owe their name to their clay-like appearance. Color from light-brown to black. Often filled with cracks filled with matter differing from the ore itself.

Dr. Percy says that, in Great Britain, when they are deep brown or black, and contain about ten per cent. of coaly matter, they are termed BLACK-BAND ore or iron stones. This kind of ore is composed, essentially, of carbonate of FeO , in intimate admixture with various matters of which the following are the most frequent:—

Carbonate of the protoxide of manganese.

Carbonate of lime.

Carbonate of magnesia.

Silicate of alumina, in the state of clay.

Potash.

Phosphoric acid.

Sulphur in the state of bisulphide of iron.

Organic matter.

Little water of combination.

Geology.—Abroad they occur interstratified with the shales of the coal measures in nodules or in continuous beds. Also, in the coal fields of Yorkshire, North England, and in Scotland, and in South and North Wales. Argillaceous ores occur in the lias of Yorkshire, also in the Wealden, and were formerly raised and smelted in Sussex. And they are not absent from the tertiaries. They are dredged up off the coast of the Isle of Wight.

In South Wales the shales adhere to the ore, but after exposure fall off.

In the United States, these clay iron stone, or carbonate ores, are found in the Lower Devonian, more extensively in the sub-carboniferous, and in the actual coal measures. The latter division includes the black-band of Pottsville, hereafter described, which is in the southern anthracite coal field of Schuylkill County. So also of the black-band found in Elk County, Pa., overlying the Wilbur coals, and in McKean County, where it is interstratified between the coal benches or layers. So,

also, in Muhlenburg and other counties in Kentucky. There is in this country but little of this black-band, and it is doubtful, according to Dr. Percy's definition of the black-band of Scotland, that it is, economically, the same ore.

On examining some of the Scotch black-band at the exhibition of 1851, a Prussian mining official gained sufficient information to recognize the same ore in Westphalia, which had previously been considered as only a useless shale, but the further discovery, according to Percy, has been made that some of the ore in this locality contained as much as forty per cent. of phosphate of lime.

Various pyrites, zinc blende, and millerite, galena and sulphate of baryta, have been found in cavities and in septarian divisions, in the argillaceous ores of British localities. (See Appendix C.)

Black-band.

This ore is said to exist in Tennessee, ten miles above Lewisport, in Hancock County, Virginia, and Muhlenburg County, Kentucky; but we have not succeeded in obtaining any specimens from worked mines. Also in Mahoning County, two miles northwest of Youngstown. It exists in uncertain quantities in Elk County, and McKean County, and in other places in Northwestern Pennsylvania. There is an inferior quality, but yielding 25 per cent. of iron, in the Frostburg, Maryland, Basin. Near Pottsville, Pennsylvania, it has been mined, and in unusually large masses or layers; but it seems to have been, as the miners say, "*pinched out*," and it is not worked at present. Hopes are entertained of again opening upon a new vein or bed in the same vicinity. We have obtained some very large and satisfactory masses. One presented us by Mr. Lanagan, proprietor of the St. Clair Furnace, has a large number of very beautiful impressions of fern leaves in the ore itself. The ore worked well, and produced, when mixed, a very satisfactory iron. The largest mass we have seen was, perhaps, 22 inches in thickness, and apparently nearly homogeneous; but we understand that the ore

was thicker (30 inches) in other places. The following are the analysis and opinions of Messrs. Booth and Garrett, the analysts:—

PHILADELPHIA, Dec. 27, 1866.

MR. E. W. MCGINNES, *Pottsville, Pa.*

DEAR SIR: We have carefully analyzed the sample of Iron Ore you sent us through Mr. Hart, and find it to contain, in 100 parts, as follows:—

Protoxide of Iron	50.44—Metallic Iron 39.23.
Do. Manganese	5.17
Alumina	traces.
Lime	1.65
Magnesia	1.84
Carbon	2.98
Silex	1.95
Sulphur	0.19
Phosphorus	0.13
	<hr/>
	64.35

The remainder is carbonic acid with a little water.

This ore, when thoroughly roasted, will yield over 50 per cent. of metallic iron.

The sulphur and phosphorus are both in small quantity, and in such proportion that the red-short and cold-short tendencies of the metal would probably neutralize each other.

The diffusion of 3 per cent. of carbon through the ore, will both diminish the *cost* of roasting, and render it more effective, while the percentage of manganese is sufficient to greatly facilitate the operation of fluxing. This ore may therefore be pronounced to be a black-band of very superior quality.

Yours respectfully, BOOTH & GARRETT.

Some distance, perhaps two miles, from the McGinnes vein, other appearances of black-band ore of the same general quality have been taken out, but in thin plates which, however, indicate that quantities very large, if not larger, than those already found, may, at no distant time, be met with in either the same vicinity of the McGinnes mine, or in places not far off.

[A good quality of black-band always furnishes good pig metal, and is, after being well roasted, an excellent material in the blast furnace; it is more inclined to make gray foundry iron than any other ore; besides that, it works exceedingly well in the furnace.]

The value of an extensive bed of true black-band of a thickness equal to that discovered at Pottsville, may be appreciated when it is remembered that in the seven

principal black-band measures of West Scotland, the thickest, that of the celebrated Airdrie black-band, is only 16 inches, and the Bellside and Calderbank, or Kennelburn black-band, either of which being only six inches thick, can be worked to advantage and profit. The following analyses of Scotch bands show the elements of similarity between the American and the Scotch.*

	1.	2.	3.	4.
FeO Protoxide of iron . . .	46.53	50.73	43.37	37.07
Fe ² O ³ Sesquioxide of iron . . .	.....	0.45	4.10	.....
MnO Protoxide of manganese . . .	2.54	1.86	1.50	0.23
Alumina	0.97	0.26	6.05	.....
Lime	2.41	2.52	3.00	6.61
Magnesia	1.39	1.26	0.25	7.40
Carbonic acid	30.77	33.89	30.50	36.14
Phosphoric acid	0.69	0.73	trace	0.23
Bisulphide of iron	0.38	0.38	1.56	trace
Water	1.47	.....	0.58	.....
Organic matter	10.46	6.41	6.25	9.80
Insoluble residue	2.27	0.72	2.80	2.70
Per cent. of metallic iron . . .	99.88 36.39	99.21 39.84	99.96 36.49	100.18 28.83

No. 1. Red Shag Ironstone, Shelton, North Staffordshire.—Dick.

No. 2. Red Mine, Apedale, North Staffordshire.—Dick.

No. 3. Black-band, Abercarne, Monmouthshire.—Rogers.

No. 4. Coal brass, South Wales.—Price and Nicholson.

The value of these ores is enhanced because of the ease by which those containing much carbonaceous matter may be calcined without much or any additional fuel. But they are subject to great variations in thickness and composition over a very small area. The Airdrie black-band, eleven miles east by north from Glasgow, is workable only within an area of ten square miles, when its composition is changed, being replaced by a thin coal. The slaty black-band is represented in Linlithgowshire, farther east by north, in like manner by the Boghead cannel coal. The yield is on an average of 2000 tons calcined ore to 1000 tons pig iron per acre of one foot thickness. In North Staffordshire black-band occurs in beds from four to nine feet in thickness, and

* Bauerman.

is largely exported, in the calcined form, for use in the South Staffordshire furnaces. In South Wales it is found in numerous small irregular beds, more especially in the western part of the coal field. In Europe it is found—not pure, however—in the Rhenish and Westphalian coal fields.*

*Earthy Carbonate Ores, and Calcareous Carbonate Ores,
Impure Earthy Limestone Ores.*

These ores are variously composed, as above suggested under ARGILLACEOUS IRON ORES. They vary in color, and many are peculiar to the central and western coal measures of Pennsylvania and southern and eastern parts of Ohio, and to Kentucky. Some are a light grayish-blue, compact and granular, and so much like bluish limestone as easily to be mistaken for it—as, for instance, at Johnston, Cambria County; others all shades of gray, brown, and bluish-black, and even green, according to the condition or prevalence of either of the substances mentioned (p. 50). The greenish shades are due to prevalence of the protoxide of iron, and of some other elements. They are essentially composed of iron, carbonic acid, lime, alumina, silica, and organic matter.

Having already noticed the American BLACK-BAND (so-called), we give some localities of the successfully worked mines of carbonate ores, or earthy calcareous carbonates, as follows:—

Earthy Carbonates, or Calcareous Carbonates.

In Vinton County, Ohio, fourteen miles west of Atkins; around Hampton railroad station, Clinton township, same county. Great amount in Jackson County, Gallia County, Lawrence County, Greenup County, Kentucky. In Green County, Western Indiana.

Johnstown, Cambria County, furnishes a large amount of calcareous ores, with carbonate of lime enough to flux the ore without the addition of any limestone. The ore

* Bauerman.

is roasted in great heaps in open air, and then appears like a red ore; before, however, it is a bluish-gray ore and much resembles limestone in appearance. A hard blue carbonate lying on limestone beds in the coal measures fifteen miles northeast of Kittanning, Armstrong County, Pennsylvania, and in Mercer County. "Red limestone ore or buhrstone ore" on south line of Clarion County. A soft ore of this nature four miles north of Harrisville, Butler County, Pennsylvania. Five miles south of Clarion, Clarion County, and four miles west. Also, in Venango County and other places in Mercer County. There is red fossiliferous limestone ore lying between the coal measures in Butler County, northwest part, on Shipping Rock Creek at the Falls.

There are ores which are mixed carbonate of iron and lime, and can scarcely be said to be true carbonate of lime and iron, but more of carbonate of iron and some lime with carbonaceous matter and organic matter, together with alumina and silex, and may be called carbonates of iron modified by the other substances mentioned. They may be called carbonate ores or carbonitic ores, though not true carbonates of iron. They occur, as worked, in Butler County, south of Clarion County, Lawrence County, at Newcastle. A soft brown and hard blue mixed carbonate ore at sixty-two miles from Pittsburg, in Clarion County, cropping out among the coal measures when it becomes altered or hematized. In Frostburg coal basin, Alleghany County, Maryland, "Rock and Kidney" carbonate ores, about two miles northwest of Youngstown, and also in Mahoning County, Ohio; in Nelson, Bullitt, and Greenup counties, Kentucky. A gray carbonate, Estil County, Kentucky. In many places where it is not fully worked or worked at all, it is abundant. Similar ores are mined at Brandonville, northeast part of Preston County, and in Monongalia County, Virginia. In eastern part of Taylor County, Virginia, on Baltimore and Ohio Railroad, southwestern Pennsylvania, in Fayette County, six miles south of Uniontown, and at Dunbar Gaps, same county, and two miles east of Union. In northern part of Somerset County and in Westmoreland County, vein running north and south, dipping east-

ward and westward near Chestnut Ridge, several miles south of Ligonier, Westmoreland County, Pennsylvania. (Appendix D.)

7. Bog Ores.

New York.—Near southeast of Helena, St. Lawrence County.

New Jersey.—Tertiary deposits of Atlantic sea board, especially bordering Little Egg Harbor River in southern part of the State. Near Milton, Sussex County, in *Delaware*, and a few miles northwest of Georgetown, in the same county.

Pennsylvania.—Indiana County, southeast corner of the county, around Armagh, there are shell and bog ores. *Clarion County*, four and a half miles south of Reimersburg, near southern line of the county. The finest examples of the ore are in Fayette County, east of Ligonier, Venango, and Butler. In *Virginia*, Shenandoah Co., and Warren Co., near Strasburg. In *Ohio*, there are several places in the southern counties. In St. Joseph Co., *Indiana*. In Kalamazoo Co., *Michigan*, northeast part of Branch Co., near and north of Quincy.

The following analyses indicate the nature of these ores:—

	Perox. iron.	Perox. Manganese.	Silica and insoluble matter.	Alumina.	Organic matter.	Water.	Metallic iron in 100 parts.	
Smuller's Furnace, Venango Co.	80.12	0.50	3.80	trace	2.00	13.00	56.08	Brownish yellow, soft and pulve- rulent.
Hickory Furnace, Butler Co.	78.60	0.40	4.80	trace	2.00	14.00	55.02	Cinnamon brown, brit- tle with plates of hematite.

The Jersey and Delaware Bog ores contain more organic matter and phosphates, but have the same physical appearance and less metallic iron.

8. Peculiar Ores.

Just south of Napanock, Ulster County, New York, is a peculiar ore, dark gray, massive, homogeneous, con-

taining little geodes of sulphide of iron, and sometimes markings apparently, but not truly, fossil; also with lenticular pieces of clay slate.

In Pottsville, Pennsylvania, there is a so-called black-band of a grayish color, containing not more than twenty or twenty-two per cent. of iron, with silex, and alumina, and organic matter, and which, though it seems to be nearly exhausted, may occur in larger quantities, as it obeys no known order of ore-position. It has been and was, until very lately, worked with some advantage.

Manganese iron ore from near Knoxville, Tennessee, has been mined and worked into a very fine spiegeleisen metal, which from all appearances is superior for steel manufacture to that of spiegeleisen which contains zinc, and from what we have heard, quite equal to the German, which is imported to Troy for the Bessemer works, where we have been informed that the German spiegeleisen, notwithstanding it is dearer, can be used more economically than the Franklinite spiegeleisen. From an analysis of this Tennessee ore, we have no doubt but that the iron would answer well in the process above alluded to.

There is also a very fine manganese iron ore from Lake Superior, used in a furnace in Alleghany City under the management of Benjamin Crowther, Esq., with excellent results. It is taken out in several places not far off from Ontonagon. Contains about fifty per cent. iron.

At Pilot Knob, Missouri, there are mined large quantities of a very hard, fine-grained ore, which will strike fire from a steel with facility almost equal to that of a flint, therefore very siliceous and containing also alumina, the peculiarity of which consists in its powder, which is a bluish-gray somewhat like a light slate color. It contains fifty-five per cent. iron, and is not magnetic. The iron from it is said to be red-short.

There is a peculiar fossil ore in the rolling country ten miles north of Blossburg, Tioga County, Pennsylvania.

A fossil limestone ore, "from beds in the coal measures," several miles east and ten miles northwest from Kittanning Mountain, Armstrong County, Pennsylvania.

There is a "bone ore" in Preston County, Virginia,

rather unusual. There is a clayey and siliceous carbonaceous ore, of a singular kind, mined at Zaliski, Vinton County, Ohio, and in Greenup County, Kentucky, and in some other places around. There is also the unusual occurrence of a light cream-colored carbonate of lime and iron ore in solid homogeneous masses amid the dark brown nodular hematites of the mines at Ironton, Lehigh County, Pennsylvania, referred to under Brown Hematites; sp. gr. 3.653, while that of the best nodular ore in the same hill is 3.173. A crucible reduction gave 46 per cent. iron of excellent quality.

Review and Practical Remarks.

[Upon the quality and price of iron ores, the success of an iron manufactory mainly depends; and these ores should be considered in every relation before a dollar is invested in any improvements, of whatever nature. In the United States, the manufacture of iron presents greater comparative advantages than in Europe and other parts of the world, so far as the natural deposits, ore and mineral coal, are concerned; nevertheless, great caution is required before a working plan is set in motion. It is true, native material is more abundant, and of better quality, in the United States, than anywhere else; but labor is more valuable; and, therefore, in no part of the world are so much attention, industry, and intellect required to carry on iron establishments. The cost of iron is, to a greater degree than in any other manufacture, represented by wages, paid by a single manufacturer; therefore, great responsibility rests upon those who engage individually in such an enterprise.

The quality and quantity of the ore greatly affect the prosperity of the local, as well as that of the general iron business. Its quality may be improved by scientific knowledge; its quantity by industry: but where this knowledge is wanting, the rule is, never to venture upon the working of bad or strange ores. Where this rule is disregarded, failure in the first instance is attended by failure in all the subsequent manipulations of the manufacture. This frequently occasions losses to the producer

which he is unable to bear, and brings ruin upon individuals who deserve a better fate. Ores, whose qualities are not yet known, should be treated with the utmost caution, and we should use every means to investigate their nature before we enter into extensive operations. In fact, until we feel perfectly safe, these operations should either be suspended, or abandoned altogether, for the first is generally the smallest loss. Ores of acknowledged good quantity are sometimes so far removed as not to afford an easy market, or so much manipulated that the profits derived from working them are small; or they are attended by other disadvantages. In all cases, it is safer to start business with good ores than to run the risk of an experiment. If the profits are small, the consolation of sustaining no loss is at least a great benefit. We shall make a short review of the different kinds of ore which the United States afford to the manufacturer.

a. Magnetic Oxide of Iron.—Black magnetic ore is found, in the State of New York, on Lake Champlain and Hudson River; in Vermont, at Bridgewater and Marlborough; in New Hampshire, at Franconia; in New Jersey and Pennsylvania, in large quantities; in Missouri and Wisconsin; and abundantly found in Oregon, somewhat in California, and New Mexico. This ore is generally rich; and one ton and three-quarters to three tons of ore produce, on an average, one ton of metal. It very seldom affords cheap pig metal, on account of the expense of roasting it, and of working it in the blast furnace. If we want the best quality of pig metal from this ore, it must be carefully roasted, and under all conditions worked by cold blast with charcoal. By proper treatment, it affords the very best and safest kind of bar iron; but by carelessness, or by an injudicious saving of fuel, very short, brittle iron. By careful roasting, and the cold blast, Sweden and Russia furnish excellent iron; but all experiments of raw mine and hot blast have, thus far, failed to produce from this ore the best quality of iron favorable to the market. Where we want good bar or wrought iron, and are not too particular in relation to expense, this ore may furnish a solid foundation for a prosperous business.

b. The next in quality is the *Sparry Carbonate of Iron*. Spathic ore is the most expensive material from which iron is manufactured, on account of the various and expensive manipulations which the production of a good marketable article renders necessary; gray pig metal it will scarcely yield by any means, and the application of hot blast is so injurious to its quality, that all experiments have yet failed to make that modern improvement available. But by careful treatment of the ores, cold blast in the furnace, and proper manipulation in the forges, this ore yields a bar iron unsurpassed in strength, and furnishes steel with extraordinary facility.

c. Specular Iron Ore.—This ore is, in many respects, the most valuable of any; for its application is very simple, and the iron it yields is the strongest and most tenacious kind known in the world. Where it can be bought at reasonable prices, it may be considered the most advantageous for the individual manufacturer.

d. Hydrated Oxide of Iron—This class, together with the mineral coal deposits, constitutes to the present generation, and will constitute, in a far greater degree, to future generations, a solid foundation of wealth, comfort, and happiness. Its sources are inexhaustible, but its quality is of such a nature, that it constantly requires the mental and physical exertions of the manufacturer of iron.

It affords an easy and cheap material, and the better varieties yield excellent iron in the blast furnace and in puddling furnace and forge; but we have to be careful in the selection of the ore beds. The eastern ore is generally of prime quality; so is that of some parts of Ohio; that of Tennessee and Alabama is of as good a quality of this kind as one could desire; but the outcrops of the coal formation, the pipe ores, and bog ores, are to be carefully selected in reference to quality. This kind of ore in the older rocks is generally good, but where it is derived from more recent deposits, it contains some of the original matter from which it is decomposed. The pipe ore is decomposed sulphuret, and frequently we find a core of pyrites in the centre; then the ore furnishes hot-short iron; but, carefully roasted, the sulphur of the

pyrites can be largely volatilized. The hydrates of the coal formation are mainly derived from spathic iron, and frequently contain carbolic and sulphuric acids, which impair the quality of the metal, but can be removed by a careful roasting of the ores. Bog ores, which mostly contain phosphoric acid, are for the manufacture of pig metal, incurable, for the phosphorus cannot be separated by roasting; but this separation can be effected in the forge, and hence, deserves consideration.] The pig iron produced is generally applied, in Canada, to the manufacture of railroad car wheels, of which some were shown in the international exhibition 1862, which had run 150,000 miles without exhibiting much wear.

[The body of this ore may be divided into two geological classes; one class belongs to the transition or secondary rocks, and the other to the tertiary and more recent deposits. The first is generally of better quality than the second; but no more definite rule can be given in relation to them. It is generally found in large beds or irregular veins, for which reason the working or raising of the ore is cheap. Where this is not the case, it is best not to commence operations.

Above all things, it is necessary that those who intend to start on a new locality, should take counsel from experienced men as to the quality and richness of the ore; and should the ore happen to average a given quantity of iron, and should the price of an amount of ore sufficient to yield a ton of iron, be but six dollars, the business may be safely attempted, and may, with industry and care, be successful. However profitable local advantages and good times may make the iron business, to those who find themselves surprised by a sinking market and limited means the losses are great. Against this danger, good quality of the product is the safest guard; and if to this advantage, that of cheap ore can be united, most difficulties can be successfully met.

e. The Compact Earthy Carbonates—Argillaceous Ore of the Coal Formation.—This ore is very abundant in the large western coal fields, and will be a source of iron so long only as they can be wrought at reasonable prices; the mining of this kind of ore cannot be considered a safe

business, for the raising is generally very expensive, and the roasting and smelting difficult. But where it can be raised at low prices as in some localities on the Alleghany River; and where the quality of iron is of no consideration, it may serve as a source of cheap iron, and therefore be considered valuable. But we must warn those who are not acquainted with the working of this kind of ore, that they will generally experience unexpected and considerable difficulty.

The remaining kinds of ore are of so small amount as not to require any further attention than that which has already been paid to them under previous mention. Where favorable localities offer themselves, an enterprise based upon such ores may be hazarded, but with due consideration of price and market; for iron manufactured from such fancy ores is generally of an inferior kind.

Mining of Iron Ore.

The mining or digging of ore does not differ much from other mining operations; and therefore a general description of mining may suffice in this particular case. However, we shall endeavor to present a clear view of the subject.

Mining is an art; "it is a highly cultivated mechanism," says Andrew Ure. An adequate idea of the high cultivation to which this branch of skill and industry has been brought cannot be exhibited at one view, because there is no one point of view from which this art can be completely sketched. The subterraneous structures present some of the most interesting monuments of the genius of human enterprise. Cultivated, for many centuries, under the guidance of science and industry, they are not, and cannot be, however great and ingenious, the objects of panoramic representation. The philosophical mind alone can contemplate and survey them, either in whole or in detail. And therefore those marvellous regions, in which roads, often many miles long, are cut and highly perfected, are unknown to the mass of the people, and disregarded by men of the outer

world. When chance, curiosity, or interest induces such to descend into these dark recesses, they merely discover a few insulated objects which make a vague, indefinite impression on their minds; but the symmetrical disposition of the minerals, and the laws which govern geological phenomena, which serve as guides to the skilful miners, they may not recognize. From exact plans of the underground workings alone can a knowledge of the nature, extent, and distribution of the useful minerals be acquired.

Among the great variety of minerals, apparently infinite, which compose the crust of the earth, science has demonstrated the prevalence of a few general systems of rocks, to which appropriate names have been given. The more recent deposit, or loose gravel and earth, is called alluvium; the most ancient deposit of this kind, diluvium; below this are the secondary rocks; the next, transition or metamorphic rocks; and the *oldest*, or *lowest* rocks, are called igneous, or primitive rocks. Every mineral deposit forms more or less of a plane, with distinct *direction* or strike, and *inclination* or pitch; the former is the cardinal direction towards which it runs, as north, south, southwest, &c.; the latter is the angle which it forms with the horizon. The *direction* of the mineral deposit is that of a horizontal line, drawn in its plane. Hence, the lines of *direction* and *inclination* are at right angles to each other.

Masses are mineral deposits not extensively spread in the form of planes—mere regular accumulations, rounded, or spheroidal. Masses generally occur in the primitive rocks.

Nests, *Concretions*, or *Nodules*, are smaller or larger masses of mineral found in stratified rocks, often kidney-shaped, tuberous, round, or spheroidal.

Large veins are called *lodes*; they are seldom parallel on their opposite surfaces, and sometimes terminate like a wedge; their course often varies from that of the strata in which they lie. Lodes sometimes pursue for a distance the space between two contiguous strata, and then divide into several branches. Lodes of iron ore are found in almost every geological formation.

Veins are small lodes, which often traverse the strata of the transition rocks, but generally run parallel in the coal measures and more recent formations.

Iron ore is met with in all the different geological eras; but, as we have already intimated, under different forms or conditions, in different geological formations. Among the primitive rocks, we find magnetic ore and specular iron, chiefly congregated in masses or beds, sometimes of enormous size; as, for instance, the magnetic ore on Lake Champlain. In transition rocks, we find red hematite and sparry iron ore, generally in veins or lodes; seldom in masses; and in the secondary the true brown hematite. In the coal measures, we find brown iron ore and yellow iron ore in all varieties, globular and kidney-shaped oxide, and gray or dark compact carbonate, generally in veins of greater or less extent. Alluvial and diluvial iron ores are the clay ores, granular ores, bog or meadow ore, &c. The ores which belong to the primitive period always have a metallic aspect, bright lustre, and furnish the richest and purest iron. The ores of the transition and secondary rocks furnish less iron, but it is generally of the most profitable kind. The more recent the age of ores, the poorer they are, until, becoming more and more earthy, they form alluvial soil.

An acquaintance with the general results, collected and classified by geology, must be our guide in the investigations of mining. This enables the observer to judge whether any particular district contains iron ore, or where this ore can be found. For want of such knowledge, many persons have gone blindly into researches which were, in their nature, absurd and ruinous. Geology teaches us that in primitive rocks no stratified or sedimentary veins can be found; neither bog ores, nor fossil, nor calcareous ores. Transition rocks contain veins of spathic iron and specular iron, but the veins run either between two different strata, or traverse the strata at indefinite angles. The coal measures generally contain iron ore, but no magnetic ore, spathic iron, specular iron, or brown hematite, except a little at outcrop, as in some middle counties of Pennsylvania; but this is not a true

or usual brown hematite, but a variety. We must be satisfied with the poorer hydrates resulting from the decomposition of the compact carbonates, or the decomposition of limestone and the carbonates themselves. Alluvium and diluvium furnish only bog ores, which frequently assume the form of veins and masses where the ferruginous waters descend upon limestone beds, and deposit their iron upon the limestone, in channels or "domes."

The *instruments or tools for mining* are the following: The *pick*, Fig. 1, made, according to circumstances, of

Fig. 1.



Miner's pick.

Fig. 2.



Miner's mallet.

various forms; but one point is generally edged, and the other pointed. In hard material, as sparry ore, or compact magnetic ore, the edged point is of no use. The coal pick is more slender, and the point more elongated. The *mallet*, Fig. 2, is used for driving wedges, and striking the hand-drill. The *wedge*, Fig. 3, is driven

Fig. 3.



Wedge.

Fig. 4.



Sledge.

into crevices or small openings, made with the pick, to detach pieces from the rock or mine. The *sledge*, Fig. 4, is a mallet of from five to six pounds weight, and is used to break larger pieces of rock or mine. Fig. 5 represents a miner's *shovel*, which is pointed, so as to penetrate the coarse and hard fragments of minerals and rocks. All these tools should be well steeled and tempered, and kept in good repair.

Fig. 5.



Miner's shovel.

Besides these, the miner requires the following *blasting* tools: A *hand-drill*, Fig. 6, which is a bar of iron or

Fig. 6.



Hand-drill.

Fig. 7.



Tamping-bar.

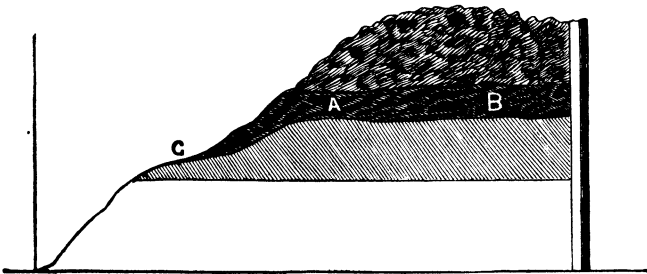
steel, edged at one end, and headed at the other—both well hardened and tempered; the *scraper*, a small iron rod, with a square hook on one end, to take the *boremeal* for rock dust out of the hole; and a *copper needle*, which is a simple wire, one-fourth of an inch thick, somewhat tapered at one end. Many miners are in the habit of using iron needles, but these are very dangerous, and should not be employed; even limestone rock is no security against accidents from self-discharges. The *tamping-bar*, Fig. 7, is a bar of round iron, with a groove to fit the needle.

A few remarks in relation to blasting may be as appropriately made here as in any other place. If there is any class of human beings regardless of their lives, the miners are that class. This remark applies particularly to blasting. Foremen, and conductors of mining operations, should be very careful and determined in their general orders, for the workmen will disregard the rules and regulations adopted for mutual safety, and bring themselves, and frequently their fellow-workmen, in danger of life and limb. Of all the blasting tools, the iron needle is the most dangerous, and occasions more loss of life than anything else in the subterranean cavities. Iron needles are very apt to fire the powder, notwithstanding the greatest care, and should not be used in any quarry or mine. The copper needle is perfectly

safe. An iron tamping-bar has occasionally caused premature discharges, but may be safely used in limestone and iron ore. To avoid the dangers arising from an iron tamping-bar, the face is frequently made of hard copper. In stone quarries, where deep and vertical holes can be drilled, the needle and tamping-bar may be dispensed with, and the hole filled with dry, coarse sand. This mode of blasting consumes rather more powder, but is without danger. In mines where no deep, and very seldom vertical, holes are available, the needle and ramrod cannot be dispensed with; this increases the necessity that these instruments should be of the most perfect kind.

The mining operation may be divided into two branches, to wit, *exploring* and *mining*. The first requires scientific knowledge; the latter, experience. After a general survey of the geological position is taken, and the situation of an iron ore or coal vein ascertained approximately, the outcrop should be minutely examined by digging, the loose ground removed, and the digging continued until the solid strata of rock are laid open. In case we do not find the expected vein, the trench may be continued either up hill or down until the mineral or coal vein is found. In this mode of exploring, it is always best to select the steepest places, because there the least covering is to be expected, and

Fig. 8.

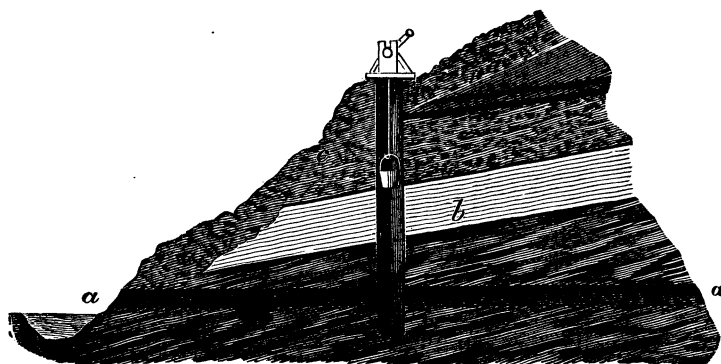


Thus, in exploring, commence at C, and work up to strike the vein A B.

to commence the workings always down hill from the supposed vein; for the mineral will naturally work down

the hill, and fragments will serve as guides. Where the fragments, or coal fine dust, called *blossoms* of the vein, cease, we may safely rely upon being near the vein. This way of exploring is very expeditious and effectual, but only applicable in stratified rocks, where the situation of the vein is indicated by the topography. Where the exploring by trenches or ditches cannot be effected, because there is too much loose ground, or alluvium, covering the strata, we proceed to sink a shaft in the most favorable place. Where the vein is so far down that but a few feet of the roof rock may be penetrated, this rock will secure the bottom of the shaft in case a thorough investigation of the mineral vein is contem-

Fig. 9.



Sinking a shaft.

plated. Fig. 9 is a section of such a shaft: *a*, the mineral vein; *b*, the overlying rock; *c*, alluvium or gravel. Such a shaft is commonly four feet wide, or, to save expense, as narrow as possible; and if the ground or gravel is not very loose, no timbering should be done until the vein is found, and the progress of the work determined upon.

The cost of sinking such shafts varies, according to circumstances, from one dollar to three dollars per foot, should the depth not be greater than from thirty to seventy feet. Beyond the depth of seventy feet, and beyond the loose ground, which requires timbering, the

cost augments considerably. If hillsides are covered with alluvium of the thickness of only six or twelve feet, and the location of the mineral vein not exactly known previous to actual search, pits or shafts may be sunk in succession up the hillside, so long as fragments of the vein in question appear in the bottom of the shaft; and if the blossoms disappear, the last pit in which they were found is continued down, until the vein is struck upon. If mineral masses, or veins, are so far below the surface that it is doubtful whether they can be reached by sinking a shaft, boring may be resorted to. Should it be ascertained that a mineral bed is so situated that a perpendicular hole may be reasonably expected to reach it, a small hole from two to two and a half inches in diameter may be driven down upon the material searched for. The boring of such a hole of three hundred feet in depth seldom exceeds one dollar per foot; from this depth to that of five hundred feet, about two dollars. The manipulations required are simply those employed in boring Artesian wells; and we shall give a short description of this interesting mode of penetrating the crust of the earth.

A brief description of the method of *boring salt wells* on the Ohio River, and its branches, or oil wells, will answer every purpose; but those who intend to engage in the experiment should employ men who, besides being well acquainted with the business, are able to conduct it safely and advantageously. When a place, where the rock is to be penetrated, is selected, a hole like the shaft of a well is dug down to the solid rock, or better, a soil pipe is driven down. Over this soil pipe a derrick from twenty-five to thirty feet high, formed of scantlings from six to seven inches square is erected. On the top of this derrick a pulley is fastened, over which a hemp rope may be laid; the one side of the periphery of this pulley is vertical to the centre of the bore hole, and a plumb-lead let down from it, ought to hit the centre of the soil pipe. The boring or penetrating of the rock is done by means of a steel drill attached to a wrought iron rod, firmly secured to the end of the rope, weighing from two to five hundred pounds weight: the vertical motion of the drill

is given by a small steam engine, and the spiral motion for the turning and lengthening of the rope, as the work proceeds, is given by the hand. This arrangement is a very good one, for it penetrates rapidly, and by it the expense of a two and a half inch hole very seldom exceeds one dollar or one dollar and fifty cents per foot to a depth of three hundred feet in moderately permeable soil. The old German method of sinking small holes by means of square iron rods, which is at present mostly employed in Europe, is very expensive, slow, and uncertain.

When the location, thickness, and quality of the mineral in question are, by means of the boring, duly determined, the following working plan may be adopted: Either to sink a shaft in the direction of the bore hole; or, where the mineral is sufficiently high, and above high-water mark of the neighboring river, to drive a level, or horizontal gallery from a convenient place on the base of the hill, and reach in that way the ore or coal bed. The manner of doing this is generally determined by a consideration of expenses, in which that of raising the material and pumping are the most important elements.

Mining, specifically considered, may be classified into open mining, or quarrying, and mining proper. Quarrying, *i. e.*, workings in the open air, present few difficulties, and occasions little expense. This method is, at present, generally practised in the United States for digging iron ore, and will not, for some time to come, be superseded by any other method; for there are immense deposits of ore which can be reached in this way, and present of course greater advantages than underground workings. Workings in the open air are generally preferred where the deposits are close to the surface. In fact, no other method can be resorted to in this case, if the substance to be raised is covered with incoherent matter. The following rules must be observed: Conduct the workings in regular terraces, so as to facilitate the cutting down of the earth, and the removal of the mine and rubbish with the least possible expense. Guard against the crumbling down of the sides, by giving them proper slope, or by props and timber. Ditches,

or water drains, must be dug, so as to keep the workings dry, and prevent disturbance in wet seasons. Open workings are resorted to in quarrying limestone, digging fire-clay, bog ores, the out-crop of the argillaceous ores of the coal formation, and various other ores ; as well as in digging turf and brown coal, and formerly, some of the anthracite of Pennsylvania. The main object to be considered in open working, or in strippings, is, to remove heavy masses of earth with the least possible expense. This can be done, if such arrangements have been made that the rubbish need not be carried too far, or too high, and no shovelful of earth thrown twice. As a general rule, it may be said, that under common circumstances, one foot of stripping can be done for every inch of iron ore, and prove profitable.

Subterranean workings and mining proper, include two distinct operations: to wit, *preparatory* or *dead* workings, and those of *extraction*. The preparatory workings consist of those excavations which do not pay their expenses in the material raised; and if the value of the ore or coal yielded from them is little or nothing, the miners call such workings "dead work." They also consist in constructing drifts or levels, or pits and galleries, for the purpose of conducting the miner to the point most proper for attacking the deposit of ore, or for tracing the extent of the mineral; as well as in arranging plans for the circulation of air, the discharge of waters, and the transport of the extracted minerals. The preparatory works in mining are often very considerable, and demand, in many instances, great attention. Where ore or coal veins are small, and the operations require extension over a large field, these works frequently absorb more means than contemplated, and are not seldom the ruin of otherwise well-calculated enterprises. The exploring of small or irregular running ore veins, which are common in the coal measures, occasions great expense. Iron works based upon such deposits, should be commenced on a small scale, and a certain amount of capital should be invested in exploring expenses, before improvements of a more permanent character are made.

The ore deposits of the coal formation, in the Western States, are often very deceptive. In a comparatively small compass, they exhibit different kinds of ore ; these either belong to insignificant bodies of ore imbedded in shale, or are the out-crops of the blue carbonates, or precipitates upon limestone beds, which are never of great extent. In all such cases, the enterprising owner of iron works based upon such deposits is in a difficult situation, for the price of his ore generally exceeds his modest calculations ; the dead works absorb more means than he expected ; and the frequent change of the ore occasions disturbances in the smelting operations, injurious to the quality and price of the manufacture. In such cases, where small or unexplored ore deposits are to be used, it is the most advisable plan to follow the out-crops ; to go with great caution to underground work ; to make it a rule not to speculate upon the improvement of the ore vein ; and to drift only on those places where the quality and quantity of the ore are perfectly known, and where the operating miner works for fair prices, without extra pay for dead work. Such small mineral deposits have, besides, the disadvantage of expensive dead work, and generally occasion greater expense for superintendence, as well as greater expense for making and repairing roads.

When a mineral vein is explored, and we have determined to proceed to drifting, the first point we are required to settle is the lowest situation of the vein. If the hauling of the mineral cannot be effected from such a point, it is necessary to drain the waters, and afford the workmen dry rooms. Such points are found either by exploring the out-crop on opposite slopes of a hill, or by opening at that side of a hill whence the strongest springs issue. Where iron ore is deposited on limestone, draining may be safely effected, if we open a drift in the strongest spring which can be found within our possessions. When the plan and place are fixed, the miners dig an opening six feet in height, and four feet wide, taking care that its floor shall be below the bottom part of the mineral, and formed of solid ground or hard

rock. The open ditch, thus commenced, is not continued very far before the miners begin to timber their drift. This must be done at the very starting-point. Its object is, to prevent the slipping in of the earth, and to prevent, in winter, the filling of the open drift with snow. Both of these accidents give much trouble to miners. The timbering is done by the miners themselves; and a good miner performs this work properly; that is, he sets his posts in a straight line, and fastens his caps in such a way that a crushing of the timber neither from above nor from the sides is possible. The

Fig. 10.

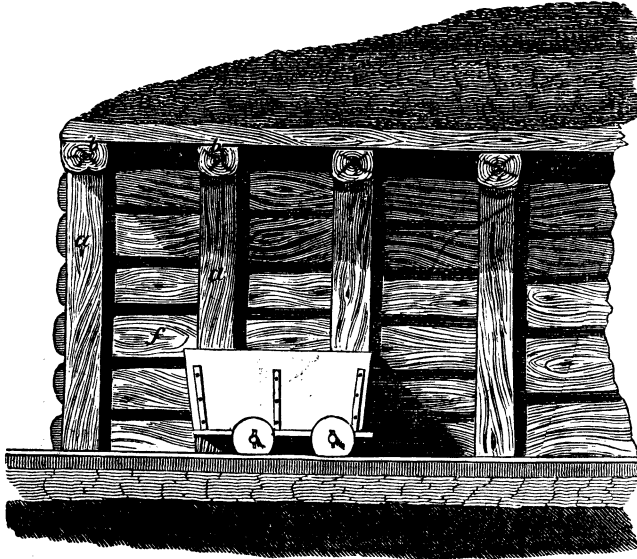


Timbering of a drift.

general way of timbering a drift is represented in Figs. 10 and 11: *a, a, a, a, a* represent posts, generally six or six and a half feet long, somewhat slanted in the view, so as better to resist the side pressure. The caps *b, b, b, b* are split timbers of ten or twelve inches in diameter, five feet long, and on each end is a shoulder "notch" in which the posts fit. The posts must rest on solid rock when possible, to prevent their sinking. *d* represents a water drain covered with planks; and *e, e* the

rails of a tram-road, made of sawn timbers, planks, or iron rails, or of flat bar iron spiked upon timber. *f, f, f, f, &c.*, are split timbers from two to three inches thick, which cover the caps and posts, to prevent the dropping

Fig. 11.



Timbering of a drift.

in of the gravel and stones. The frames, consisting of two posts and one cap, are generally one yard distant from each other. In coal drifts the width is often eight and even ten feet to allow the passage of loaded cars. That part of the structure which is outside of the hill, is to be covered with earth to keep the drift warm in winter, cold in summer, and prevent the decay of the timber.

Coal and iron ore are minerals which cannot bear expensive preparatory works. We shall confine our remarks to the most simple forms of mining operations, for a thorough description of extensive mines is not necessary. Drifts and shafts, constructed in the cheapest possible way, are the general avenues of excavation, and to

these we shall confine our attention. If an ore or coal deposit cannot be reached by drifting—either because the deposit is under the general water level, or because the extent of our property does not permit us to reach the lowest point of the deposit—we are forced to work by shafts or slopes, and hoist minerals and rubbish, as well as the waters, by machinery. Shafts are simply vertical excavations sunk to the mineral vein (Fig. 9); slopes are inclined shafts. A work-shaft is larger than an exploring shaft, often exceeding ten feet square. Their dimensions depend entirely on the amount of matter to be raised. Coal shafts are generally large, so as to permit the ascending and descending wagon to pass; while ore shafts are sufficiently large if they permit the passage of a box which will contain from five to seven hundred pounds of ore. The drift is the horizontal passage to and in the mine, whether it be from the hill-side or from the bottom of the slope or shaft. The timbering of shafts, as well as that of drifts, varies in form, according to the nature and locality of the ground which they penetrate, and the purposes which they are meant to serve. The shafts to be secured by timber are either square or rectangular; this form, besides being more convenient for the miner, renders the application of timber more easy. The wood work consists generally of frames, the spars of which are from six to ten inches square, and placed from two to three feet apart; seldom, except in very soft ground, placed more closely. The frames are always placed so as to stand at right angles to the axis of the shaft. The mining operations, which extend from the lowest point where the shaft reaches and sinks through the mineral, are not in the least different from those pursued in drifts, and will be included in the general explanations. Waters, if not extracted by a separate drain, must be hoisted either in large buckets, if the amount is small, or, if large, with pumps.

It is of considerable importance what kind of timber is used in mines. In ore mines, locust, white oak, and red oak are preferable; but in coal mines, pitchy pine is the most durable. Unless otherwise stated in the con-

tract, it is generally understood that miners put the timber in themselves. But the timber is to be delivered at the mine, or at the mouth of the pit, ready split, and cut into proper lengths.

The cost of drifting varies according to the matter to be penetrated. In slaty rock, primitive slate, secondary slate, shale, &c., a drift six feet in height, and four and a half feet at the base, costs seven or eight dollars a yard running measure; tools and gunpowder found. If ore or coal is met with, nothing extra is paid for it. It belongs to the owner, and should be put aside. Drifts in primitive and transition rocks will cost from five to fifteen dollars a yard, if tolerably wide. These rocks do not require timber, and to that extent save mining expenses. Limestones are not easily penetrated; they cost from five to ten dollars a yard; require, oftentimes, strong timbers, and are not very safe. Drifts may be put into coal veins at from two to three dollars, according to roof and floor; strong roof and hard floor make the cheapest and best drifts. The sinking of shafts is expensive. Hard primitive and transition rock averages from fifteen to thirty cents a cubic foot; and, in the coal formations, from ten to twelve cents, besides timbering and timber. In coal formation and limestone, shafts are frequently very expensive, on account of the water which, accumulating in the bottom, disturbs the works going on. When such troubles happen, and the pumps employed are not strong enough to hold the water, strong frames, and waterproof planking, should be placed so as to keep the fissures closed. Pumping machines, however, are so improved, that comparatively little trouble is experienced when everything is properly managed.

Besides the expense of drifting, and that of dead levels through the mineral, air shafts in deep workings occasion great expense both of money and of time. They are indispensable where bad air troubles the diggers, and are needed in coal pits to prevent explosions, which are often ruinous both to the men and to the works. Davy's safety-lamp is but an imperfect prevention, and should not be depended upon. Good air shafts can be erected

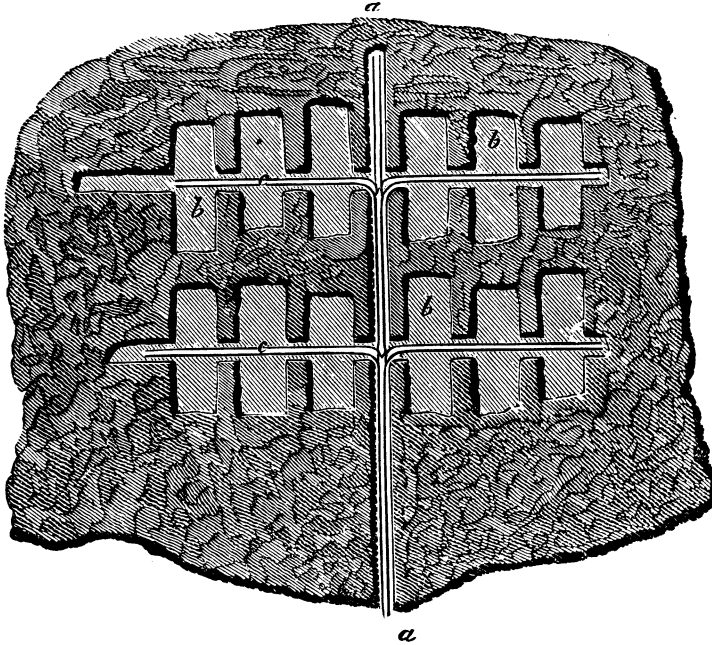
everywhere ; and that economy is misapplied which seeks to dispense with them. Fresh air, besides the advantage it affords of greater security to the lives of the workmen, preserves the timbering of the mines better than anything else.

If an ore vein is both regular and of great extent, a gallery or level may be driven into it far enough to permit the construction of a number of chambers or rooms, for the miners. Where the vein is thin, say from ten to fifteen inches, let us assume that one miner is able to dig on an average one ton of ore in twelve hours : If fifty tons are needed in twenty-four hours, and if the mining is carried on in the daytime alone, twenty-five rooms are required ; but if carried on both day and night, half that number is sufficient. One room is seldom smaller than five or six yards, and, if the roof is solid and strong, sometimes from twenty to thirty yards wide. Two miners generally occupy one room. If this calculation is correct, and rooms of fifteen yards, with five yard

pillars, adopted, it will require a drift of $\frac{20.25}{2} = 250$ yards

long to deliver a safe and regular supply of fifty tons of ore a day. Here we may economize in dead work, but if done, it is on account of regularity and order. Fig. 12 is a plan of such a mine excavated in nearly a horizontal stratification. The main drift *a, a* may be in the lowest axis or centre of the vein, and the waters from all the rooms *b, b, b, &c.*, can be conducted, by means of the branches *c, c*, to the main drift ; but where this is not the case, the branches should be slanted towards the mouth, with due regard to the free discharge of the waters. The latter arrangement generally has the disadvantage of limiting rooms to one side of the branches, and not unfrequently of limiting branches to one side of the main drift. This circumstance, of course, increases the expense of dead work. If rooms, in this way of working, are exhausted, and no extension of the branches contemplated, the pillars may be taken out by commencing at the furthest end (which can be done with perfect safety, if the roof is strong), and the rubbish piled so as

Fig. 12.



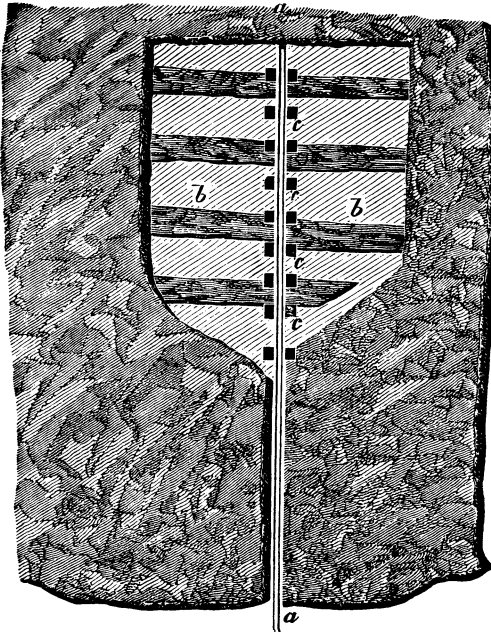
Ground-plan of the interior of a mine.

to support the sinking roof. In case any extension of branches or main drift is projected, it is better to leave the pillars standing until a final abandonment of the mine is in view. A good roof will, in this way, permit the taking out of every ton of ore.

If a thin vein of ore is overlaid by shale, which, brittle in its nature, cannot long resist the pressure from above, a different plan of mining is to be pursued. The miner opens a drift in the common way; he is not very careful in timbering it, giving it but sufficient strength to serve his purposes; he drives his level with the greatest possible advantage and speed, as far as he sees fit—twenty yards or one hundred yards; and, when he thinks this level is pushed far enough in, he opens rooms on both sides of his drift, and piles rubbish and stones against the timber of the drift, to secure the roof in case the timber gives way. He continues to take out the ore

on both sides of the drift, as far as he with safety can venture, and then recedes towards its mouth. When this is reached, there is no further use of the mine, for, if not behind him, the roof will be down shortly after he leaves. Fig. 13 represents the plan of such a drift; *a, a* is the original drift; *b, b*, excavations or rooms; *c, c, c*,

Fig. 13.



Drifting of ore.

c, timbers, against which he piles the rubbish taken from *b, b*, leaving only an opening where he is working, to carry out his ore. This plan of working is a cheap one, and answers well where an extensive out-crop of ore is at our disposal; or where the out-crop is the only valuable ore, which is the case with most of the argillaceous ores of the coal formation; or where iron ores are deposited on limestone, and do not extend into the interior.

These two are the most common plans of working iron ores, and answer every purpose where the veins can be made accessible by an out-crop of low situation; but

where the out-crop is high, that is, where the interior is lower than the out-crop, a more expensive plan must be adopted, either by shafts, when these are the cheaper method, or by a dead level, to be driven towards the lowest point of the deposit.

Upon the working of coal mines we shall treat in the next chapter, as this subject is connected with that of fuel, and differs in many respects from the mining of ore; still, in both cases, the utmost economy is needed, as each presents a great field for spending money, and as operations, once commenced, cannot be abandoned without losses. But where these operations are of a doubtful nature, the continuance of our business only involves an increase of the loss. Above all things, a careful geological survey, and local explorations, should precede every mining enterprise.

Wages for digging iron ore vary, of course, considerably, according to location and facilities; a one foot vein of magnetic ore, specular ore, and sparry iron, may be wrought at two dollars a ton, if the undermining is not too hard, that is, if the rock below the ore is soft enough to be easily cut by a sharp pickaxe; sometimes even at one dollar, if the bed is heavy, and if the ores belong to the crystallized kind. Hydrates, such as shell ores, brown iron stone, and yellow hydrate, can be dug at one dollar a ton, and, in strippings and thick veins, at a still less cost. The compact carbonates of the coal measures are the most expensive, very seldom less than two dollars a ton; they average three, and frequently even four dollars a ton, tools and gunpowder to be charged to the miners. To this item are to be added, the expense of hauling, repair of roads, ore leave, timber, dead work, and interest on the capital, which, in many cases, will add twenty-five, and, in some cases, fifty cents to the original cost. Ore leave requires attentive consideration, where the ores are poor and other expenses high. In some instances, it is beyond the power of an owner of iron works to buy all the ore lands required for the prosecution of his business, and he is compelled either to pay an ore rent, or buy the ores; both cases require

caution, however simple the business appears to be. Still, there may be cases where ore grants and buying of ore are preferable to the purchase of ore lands; as, for instance, where it is impossible to ascertain the extent of ore, or where the price appears to be high, or where there is lack of judgment on the part of the buyer, or want of means, or doubtful times and market.

CHAPTER III.

SPECIAL PROPERTIES OF IRON AND ITS COMPOUNDS.

CERTAIN varieties of carefully wrought iron approach perfect purity, but they are all more or less impure.

In form of powder pure iron may be obtained from sesquioxide of iron in hydrogen even under a low degree of heat. Then it is a dull gray, but becomes metallic in lustre under pressure and friction produced by the burnisher.

Peligo^t's plan of obtaining iron is by heating (in hydrogen) protochloride of iron, and the metal thus obtained is in filament form, compact, malleable, and almost as white as silver.

Berzelius' plan (from wrought iron of commerce) is by mixing iron filings with one-fifth of their weight of sesquioxide of iron, and heating under pounded glass (free from metallic impurities) in a covered and luted Hessian crucible, during an hour in a smith's fire, with coke as the fuel. Thus made, it approximates silver in whiteness, is extremely tenacious, softer than ordinary bar iron, in fracture scaly, conchoidal and occasionally crystalline.

Percy tried this with somewhat different results. He cut very fine wire in small pieces and treated it, as above, under plate glass. A well melted button was found at the bottom of the crucible. It was nicked across the middle and then broken, fracture largely crystalline and grayish-white, metal soft and malleable, a portion was hammered and then rolled out cold into a thin strip, the

edges were jagged. Specific gravity before rolling 7.8707, and afterward 7.865. Percy thinks it was not pure, as it dissolved easily in hydrochloric acid, or dilute sulphuric acid, with the evolution of fetid hydrogen.

Proling found that melted bar iron was 7.8439, whereas the same iron, in thin sheets, was reduced to 7.6, and to 7.75 in square wire a little less than .08 of an inch diameter. Berzelius supposed the anomaly resulted from repulsion between the thin iron and the water, but the iron was freed from all foreign matter by cleansing in potash. Hence he refers it to the mechanical treatment of the iron after fusion. Specific gravity of copper is affected in the same manner.

Percy says, the only pure iron he has met with was produced by electrolysis.* Mr. Henry Bradbury furnished him with laminæ deposited upon copper plate, to protect it in printing.

The solution employed contained protochloride of iron and chloride of ammonium. The metal was thrown down as a thin, bright, and firmly adherent layer. So perfect is the laying down that the iron deposited by *acierage*, as this process is called, produces an impression as sharp as that of the copper. If not deposited more thickly than a film it is highly polished. A solution of iron containing cyanide of potassium is used in the process.

Such iron is scarcely acted upon by H Cl , or SO^3 , at the ordinary temperature, but on application of gentle heat, a scentless hydrogen is produced, which is not the case with any wrought iron.

Barruel says that he has kept electro-deposited iron in a cupboard many years, and it presented not the faintest trace of rust, though exposed to acid vapors.

Percy says, such iron rapidly rusts when exposed to the *combined action* of air and moisture. The specific gravity of this iron is 8.1393, according to careful examination by Percy. Rapid cooling had no effect to harden it, while, Percy says, there is no commercial iron even in the thinnest sheet that is not hardened, or rendered more rigid, by this treatment.

* Decomposition and precipitation by the galvanic battery.

The iron is deposited from a solution of the salt of the protoxide, such as protochloride or -sulphate, and the presence of the chloride of ammonium is supposed to be necessary to the smooth polished steel-like appearance. With a strong current and small pole much hydrogen escapes, and the precipitated metal, when of a certain thickness, is soft, spongy, and porous. If this is washed and dried over caustic potash, it smells strongly of ammonia; by heating, the odor strengthens and then disappears; by boiling the powdered precipitate in water, hydrogen is evolved copiously. Because of this action the presence of nitrogen has been suspected.

Meidenger found 1.5 per cent of ammonia. Krämer says, he found in a similar precipitate 1.49 per cent. nitrogen. Percy thinks these statements may be correct but need confirmation.

Crystalline System.—Iron crystallizes in the cubical system.

Wöhler, on breaking cast-iron plates, readily obtained cubes, but the iron had been long exposed to white heat in the brickwork of an iron smelting furnace, and octahedra were found lining the cavities of a large cast-iron roll which was unsound.

Augustin found cubes in the fractured surface of gun barrels which had been long in use.

Percy found on the surface and in the interior of a bar of iron which had been exposed for a considerable time in a pot of a glass-making furnace, large skeleton octahedra. In another case, the surface was not crystalline, but covered with a black scale, and where it was not so covered it was bright and approximating silver in appearance.

Prof. Miller, of Cambridge, found the Bessemer iron to consist of an aggregation of cubes.

It may be objected that this crystallization exists in impure iron, but a small quantity of impurity has not been found to alter the system of crystallization.

Magnetism.—Iron, when pure, readily loses any magnetic power it may have acquired.

Matteucci found that a drop of iron while melted by the hydro-oxygen blowpipe was taken up by the magnet.

Tenacity.—That of absolutely pure iron not determined. Commercial iron varies with the amount of impurity, temperature, &c., from 71,000 to 114,000 lbs. (Morin). (Appendix.)

The tensile strength, generally, has reference to one square inch of transverse sectional area. Dufour says that it is improved by the passage of an electrical current through it.

Specific Heat.—Dr. Thomson (Records of Science Ap. 1836) 0.110. Dr. Percy, quoting Regnault, 0.113795, which determination was made with an iron wire so pure as to leave no sensible residue when dissolved in hydrochloric acid.

Dilatation by Heat.—The dimensions which a bar takes at 212° Fah., whose length at 32° is 1:—

Cast iron	1.00111111	or one 900th part.
Steel not tempered .	1.00107875	“ “ 824th “
Wrought iron . . .	1.00123504	“ “ 809th “

According to experiments by Lavoisier and Laplace, steel tempered dilated more than when untempered as 927 to 926.*

Cast iron, of foundry kind, generally contracts from the molten condition to cold, or about 60° Fah., one ninety-fifth to ninety-eighth, and this allowance in practical matters must be made in all patterns for moulding, being about 1 per cent. linear measurement.

Action of Heat; Welding.—The melting point of iron is not yet determined with certainty, but has been estimated at 1550° C. by Pouillet or 2822 Fah., which is questionable. We can easily fuse it in our assay furnaces where platinum remains infusible. It has a remarkable property of remaining pasty through a considerable range of temperature below its melting point. At a red heat it may be welded, and at a white heat by pressure it unites intimately. This is welding, or union of separate pieces of the same metal below the point of fusion. Generally, other metals seem to pass quickly

* In Dr. Percy's metallurgy the coefficients vary so much from Lavoisier and Laplace, that we have supposed there must be an error in the type.

from the solid to the melted, or liquid state. Some become brittle and easily pulverizable before arriving at the melting point, and when there is a range, from the solid to the liquid point, in which metals are soft and pasty, that range is so limited that it is difficult to determine the time with any degree of certainty. This pasty condition facilitates welding. The essential requisite to be reached, before welding, is a clean, unoxidized surface upon the parts of the metal to be welded. In iron, a black oxide is formed, but this is easily dissolved into a fusible silicate by the use of sand thrown upon the surface. A resort of this kind is frequently had by the blacksmith, and the fusible silicate is squeezed out in the act of compressing the parts; but it would be extremely difficult to find a suitable flux for other metals.

There is a degree of weldability in platinum which causes that metal to be classified with iron as a weldable metal, and yet platinum passes very rapidly from the solid to the liquid state.

Copper, in a fine state of division, as when precipitated, coheres, under great pressure, into a solid mass. Copper medals have thus been struck.

Gold and silver in the state of fine powder may thus cohere.

The oxide of silver, from decomposed chloride of silver, has been hammered under heat less than fusion, and re-hammered into bars and actually Damaskeened with gold powder. This is regarded a true welding, and it may properly be thus regarded in a degree, and so even when lead, freshly cut, adheres, its adherence is analogous to the welding of iron.

Crystalline and Fibrous Iron.

After fusion, iron is highly crystalline. Even a button of one or two oz. may show large cleavage planes internally, and if slowly acted upon by dilute HCl or SO_3 , the crystalline structure may be seen upon the outside.

This is not due to foreign matter symmetrically distributed, as some have supposed. Rose has shown that dissimilar faces of quartz crystal may be corroded very

unequally by the same hydrofluoric acid; similar faces being acted upon with the same degree of intensity. The various circumstances under which iron undergoes crystallization have excited much attention, and the subject is not yet clearly settled. Percy has thrown much light upon some of the difficulties, but has not, as we shall see, entirely cleared the obscurity to the satisfaction of all.

Bar iron acquires a largely crystalline structure when exposed for a long time to a heat considerably below that of fusion.

Zinc exhibits the same characteristic, which is due to the fact that the atoms have sufficient room, by such heating, to arrange themselves into crystalline form.

Hence we can see why iron which has been heated into large masses and thus forged, may become crystalline from the long-continued internal heat.

Hammering these large masses does not destroy the crystalline structure, the internal part being white hot while the external is red. Hammering the outer, at too low a temperature, causes tenderness. As the presence of phosphorus favors the formation of large crystals, and this element occurs in most varieties of British and American commercial iron, this ingredient may largely modify the results of some experiments performed with irons otherwise of the same grade.

When iron is hammered cold in various directions, the strength is diminished and tenderness ensues, and upon the above facts of crystalline structure the cause may be based. The larger the crystals the more easily broken is the mass; contrariwise, the smaller the crystals are, the less likelihood of breakage.

“When a piece of iron has been melted, and which is largely crystalline, is cautiously hammered at a suitable temperature into a shape adapted for rolling, and then rolled into a bar not too thick, it will present either a crystalline or fibrous fracture according to the manner of breaking it, and, especially, the duration of the act.” (Percy.) If nicked on one side and gently drawn over, the fibrous appearance will be nearly silky, if nicked all round and suddenly broken, the fracture will be crystalline with only here and there a fibrous appearance. In

the operation of rolling, the crystals are drawn out into lengthened wires or bundles of wire in one direction, and the instantaneous fracture of the smallest wire will be crystalline, though exceedingly small in the crystal. The fibrous condition of bars may be shown by acids; this may be more plainly exhibited because of the silicate of iron, from which no such bars can, certainly, be said to be free, and which, being unequally distributed, causes unequally sized etchings. Time, in the process of fracture, will almost always determine the nature of the fracture.

At Shoeburyness, experiments were performed to determine the quality of iron for armor plates. What was known as good fibrous iron was shattered like glass under the impact of shot moving at a rate of 1200 to 1600 feet per second. This is Percy's view of the subject.

On the other side of the question, data have been offered to show positive change in the structure of iron, due to continued vibrations upon iron, resulting from blows long continued, or from long-continued jarrings, such as occur in artillery practice, railroad travel, &c. It is a question of great practical importance to the arts, but opinions are divided. Doubt has been had as to the previous nature of the material. Iron, which has been supposed to have acquired a crystallization by jarring, &c., may have had the crystalline form before, and the after jarring, &c. caused only *disaggregation*. When cold, as we have seen, iron, after fusion, or after arriving at the *pasty condition*, has assumed the crystalline form which rolling and drawing may only elongate but may not wholly destroy.

A case, in all essential points similar to that cited above, wherein Harland and Wolf removed broken plates from the Istrian (1867), is thus accounted for, we believe, by Mr. Colburn. It is a well-known property of all metals of which the particles crystallize after fusion, but in which the crystalline arrangement has been rolled out, or hammered out, into what we call grain or fibre, to return to full crystalline state upon the application of heat more or less approaching that of fusion. Bar iron, if overheated in the forge, becomes what is technically known as "burnt," not that the metal has been oxidized (except superficially, as

all iron is in the forge) but its fibre is gone, and it breaks short with a coarse crystalline fracture. Steel becomes "burnt" at a lower heat than iron, and, as is well known, it therefore requires more care in its working. In other words, the presence of a greater proportion of combined carbon in steel than in wrought iron, facilitates the formation of crystals at a lower temperature, notwithstanding that the absolute cohesion of the particles in the mass is much greater in steel than in iron. In cases where the power and speed of steel plate mills are insufficient to roll out a plate at one heat, it has been put back into the fire in just the state in which it is most liable to irregular and excessive heating, and when, in case of overheating, but little working remains to be put into the plate to again develop the fibre, if indeed that be possible, after the metal is once "burnt." With insufficient mill power, the case, of course, becomes all the worse with a heavy plate, and the steel plates which Messrs. Harland and Woolf removed from the Istrian were heavy plates, 10 ft. by 3 ft. by $\frac{5}{8}$ in. Unless these plates originally contained too much carbon when in the ingot, and this is a matter which may always be ascertained, we have no doubt that they were injured in the reheating furnace at the rolling mill.

But in all cases there is a ready test for the finished steel plate. It should be sheared all around, and any part of the sheared strip should bend over double in the cold state, the inner sides of the bend coming flat home to each other without cracking. All steel plates can be made to stand this test, and it should always be enforced. Where the metal withstands it, there is no doubt of sufficient fibre, and the plate may be fully depended upon for the severest use to which iron is ever applied. The omission of this essential test on the part of the makers of the steel plates, which lately formed the subject of a trial in the Crown Court at Belfast, has caused whatever distrust, in any case temporary because undeserved, may have arisen as to the strength and ductility of steel plates.*

* "Engineering." April 19, 1867.

CHEMICAL PROPERTIES AND SPECIAL EFFECTS OF COMBINATIONS AS ALLOYS.

(Atomic weight 28 (Svanberg.)

Iron and Oxygen.

"In perfectly dry oxygen, iron in a *compact* state undergoes no change at the ordinary temperature of the atmosphere," but in minute division, as when sesquioxide of iron is reduced by hydrogen at very low temperature, it takes fire when gently heated in the atmosphere, and becomes sesquioxide. Iron thus divided is said to be pyrophoric when cold, *i. e.*, it ignites spontaneously.

Experiment: pure sesquioxide of iron is prepared by adding ammonia, in excess, to solution of sesquichloride of iron, and perfectly washing the precipitate. Reduction may be effected in a glass tube by hydrogen which has passed through SO^3 and then over chloride of calcium, and fragments of caustic potash. The oxide is, previously, finely powdered and gentle heat applied by means of a spirit lamp. The iron shaken out ignites, but only so long (so Percy) as the tube was warm to the hand. There will be a variation of temperature at which the ignition takes place, due to methods of preparation and temperature at which the hydrogen passed over the iron.

Reduction (according to Magnus) of iron, in hydrogen, begins at the boiling point of mercury, and is completed between that and the melting point of zinc; within these limits the iron is pyrophoric, but is not if reduced at a limit beyond.

When the reduced iron is allowed to cool in carbonic acid gas which has displaced the hydrogen, the iron is not pyrophoric. When sesquioxide is precipitated with about three per cent. of alumina, or silica, it may be reduced by hydrogen in red-hot condition, and yet be pyrophoric, because the alumina and silica keep the iron yet in a finely divided condition.

Iron even in a compact state, heated to redness in oxygen, burns vividly, forming an oxide, said by Merchand to be Fe^4O .

Iron, if at a white heat, will burn in atmospheric air.

If atmospheric air be blown upon a piece of white-hot iron, or if one end of a bar be heated white hot and the whole be slung around the head, a series of splendid sparks of burning iron will ensue. This fact is illustrated in the Bessemer process, as will be seen hereafter, for when the carbon is burned out, the air consumes the iron itself.

Protoxide of Iron.

$\text{Fe O.}—28+8=36$ equivalents.

Said not to exist pure in separate state. But, according to Debray, it is formed when steam and hydrogen, in certain proportions, are passed over sesquioxide of iron. Thus prepared, it is black, non-magnetic, easily burning in atmospheric air. Prepared by heating dry oxalate of iron, excluded from atmospheric air, it is commingled with small portions of metallic iron, and ignites spontaneously in the air, becoming sesquioxide of iron. It is a powerful base.

It is precipitated from solutions by potash or soda, in the state of a flocculent white hydrate, which in contact with the air absorbs oxygen and becomes green, owing to formation of some magnetic oxide. There is a combination between this oxide and the alkalis KO NaO NH^4 , giving rise to ferrites of these bases. It has a powerful affinity for oxygen, and has the power of decomposing water. Thus, when a protosalt of iron is precipitated by potash in excess and the whole boiled, hydrogen is pretty copiously evolved and magnetic oxide is formed.

Sesquioxide of Iron; Anhydrous.

$\text{Fe}^2\text{O}^3=56\times 24=80$ equivalents.

Found in nature, and crystallizes in the Rhombohedral system, crystals steel gray, powder red or reddish-brown.

The minerals specular iron and micaceous iron ore are of this oxide. In thin scales, transmits red light.

Specific gravity ranges from 5.191 to 5.230, that of the artificially prepared oxyd 5.17. The artificial is non-magnetic, the native may be very slightly. When strongly

heated in contact with metallic iron, becomes magnetic oxide. It is infusible except at very high temperature, and then forms magnetic oxide. Easily reduced to the metallic state when heated to redness in contact with Carbon, CO , H , NH_4 , or Cyanogen. When reduction by any of them takes place at a low temperature, the iron is pulverulent, but when the temperature is high, a coherent mass of metal is formed, easily forged. Not necessary that there should be intimate connection between the lumps of sesquioxide and the Carbon, &c. to effect complete reduction.

Lumps, size of a man's fist, exposed several hours, imbedded in charcoal powder (coarse), at a bright red heat, are reduced to metallic iron. Magnetic oxide is first formed, and then metallic iron appears and permeates the mass.

It is largely manufactured in the state of powder, varying in color, according to method of preparation, and used as a pigment, and in the ceramic arts—produces tints of red, brown and violet.

Calcination of the following salts of sesquioxide yield fine red, dark red, and blackish-brown, viz., basic sulphate, sulphate and nitrate of the sesquioxide. It is much used in polishing plate glass. Made for this purpose by calcining sulphate of protoxide of iron (green vitriol) at a red heat, and subjecting the residue, called colcothar, to trituration and levigation.

Rouge is finely levigated sesquioxide of iron.

A fine micaceous variety of sesquioxide is obtained by carefully heating dried sulphate of protoxide mixed with two or three times its weight of common salt; wash well. Thus prepared it is not easily acted upon, even by hot H Cl .

It is insoluble in water, or in solutions of the fixed alkalies and ammonia. Dissolves in $\text{SO}^3 \text{NO}^5 \text{HCl}$; but not easily after crystallization or ignition.

The best solvent is HCl ; best done by heating the oxide to redness in porcelain crucible, closed and with hole in the cover for reduction by hydrogen or carburetted hydrogen (coal gas). Reduction takes place in a few

minutes; the metallic powder is then soon dissolved, and the protochloride may be converted into sesquichloride in usual way by boiling with a little chlorate potash, or by NO^5 . Much time is thus saved.

Appearance under Blowpipe.—In small quantities in borax bead on platinum in O. F.:—

Yellow—when hot.

Colorless—cold. With greater quantity:—

Red—hot.

Yellow—cold. With more:—

Deep red—hot.

Deep yellow—cold.

In R. F. bottle-green, and when heated in R. F. on charcoal, with addition of tin, first bottle-green, and after much blowing green vitriol-green. In microcosmic salt a small quantity of this oxide becomes in O. F. yellowish red while HOT, but on COOLING, first yellow, then greenish, and, last, colorless; with *large* addition, dark red while *hot*—brown red on *cooling*—then dirty green—and, when cold, brownish-red. The color disappears on cooling much sooner than in the borax bead. With small quantities in R. F. no change; but with large quantities *red*; HOT; on COOLING first *yellow*, then *greenish*, and last *reddish*. Treated with tin on charcoal, bead on cooling becomes *green*, and at last *colorless*.—*Plattner*. (Appendix A.)

Hydrated Sesquioxide of Iron.

Sesquioxide of iron combines with water, forming definite hydrates, losing all water at red heat. It is precipitated as bulky reddish-brown, by ammonia, and by potash and soda; the latter combine, and are difficult or impossible of entire removal; hence ammonia is generally used.

When first thrown down formula said to be $\text{Fe}^2 \text{O}^3$, 3HO . In this state it is readily soluble in acids, and amorphous under microscope. Kept some time under water becomes crystalline under the microscope; difficult of solubility, and becomes $2\text{Fe}^2 \text{O}^3$, 3HO —that is, loses half its proportionate water. When boiled in water three

or four minutes, it becomes sesquioxide of iron + HO. Senarmont (*Ann. de Chim. et du Phys.*, 1851, 32, p. 146) says that after eight days' exposure to the action of water at 160° C. to 186° C., in closed tubes, it became anhydrous. Schiff examined some which had remained more than fifteen years under water, and it had the same formula. It is much altered when kept under boiling water seven or eight hours, becoming brick red, and difficult of solubility.

Graham obtained from a solution of highly basic sesquichloride of iron, by dialysis, a nearly pure aqueous solution of sesquioxide of iron. Water containing one per cent. of hydrated sesquioxide is of a dark venous blood color. It may be concentrated by boiling till it pectizes (coagulates). In the cold this condition is effected by traces of SO^3 , alkalies, alkaline carbonates, sulphates, and neutral salts in general, but not by H Cl, NO^5 , acetic acids, nor by alcohol or sugar. The coagulum is dark red—more transparent than blood clot. Once formed, either by a precipitant, or by time, without any addition having been made to the sesquioxide (solution of), it is no longer soluble in water, only in dilute acids; that is, it is ordinary sesquioxide; so that there is a soluble as well as an insoluble form. There is also a soluble meta-sesquioxide of iron, prepared by the prolonged action of heat upon a pure solution of the acetate. The characteristic properties are the orange red color and opalescence of its solution. (Percy.)

Sesquioxide of Iron and Lime.

The oxide combines in the dry and wet way, forming 4CaO and sesquioxide of iron. It is precipitated by addition, in excess, of potash to aqueous solution of chloride of calcium and sesquichloride of iron in ratio of four equivalents to one. It is a light, amorphous, snow-white powder; becomes brown on exposure to air, because of liberation of some sesquioxide of iron; may be kept any time if air is excluded. When first produced, is slightly brown—due to uncombined sesquioxide of iron, which,

gradually, (after hours) combines, and the mass becomes snow-white, though containing nearly half its weight of sesquioxide of iron. It is unstable, is decomposed by being boiled with a soluble carbonate, or may be decomposed by CO^2 .

Magnetic Oxide of Iron.

Fe O + sesquioxide of iron. Crystallizes in the cubical system. Occurs crystallized, in nature and in furnace products, as octahedral, and Percy says, once, in rhombic dodecahedron. Powder and streak, black. Specific gravity 4.98—5.20. Fusible at high temperature. May be formed by boiling iron filings in excess with water and hydrated sesquioxide of iron, such as may be prepared by precipitating sesquichloride of iron by ammonia and washing but not drying: water is decomposed with evolution of fetid hydrogen, and this continues until sufficient protoxide is formed; so that with the sesquioxide present the proper proportion to form magnetic oxide has appeared. The product is black pulverulent hydrate of magnetic oxide, from which the metallic iron may be removed by levigation. When solid protochloride of iron is heated with an excess of carbonate of soda in a crucible, magnetic oxide is formed, and by washing with water is left in state of black crystalline powder, which may be dried forthwith.

When this oxide is put into a close vessel with only enough acid—say hydrochloric—to dissolve the protoxide, that, only, is dissolved, and the sesquioxide of iron is left undissolved.

Iron Scale, or Hammerslag.

When sheet, or bar iron, is heated red hot and bent, or put into water, the scales which are disengaged are of this nature. It is black, magnetic, and melts at high temperature. The scale is not homogeneous, but consists generally of more than one layer, and the farther inward, or away from the atmosphere, the less sesqui-

oxide of iron and more protoxide it contains. In exposure to long continued red heat as many as three layers are found, each containing sesquioxide and protoxide, but less of the protoxide and more sesquioxide on the outer, the sesquioxide increasing outwardly—decreasing inwardly.

Ferric Acid.

Fe O^3 . It is not known in an isolated state, but exhibits its presence in combination with potash, soda, and baryta. It exhibits itself when the following experiment is performed: a Hessian crucible, containing 5 grammes of iron filings (pure), is heated to redness, when 10 grammes of the powder of fused nitre are thrown in; lively action takes place; the crucible is covered and cooled; if pulverized, immediately, it may be kept in stopped bottles, but soon deliquesces. It is a violet colored mass, and is best dissolved in ice-cold water.

Ferrate of soda is produced by galvanic current upon a plate of iron immersed in solution of soda.

Ferrate of baryta by addition of nitrate of baryta, or chloride of barium, to ferrate of potash.

Iron and Water.

At ordinary temperature water has no action upon iron, even in finely divided state, provided air be excluded; but the pulverulent metal decomposes water at much below 100°C . Decomposition begins at 55°C ., and increases with increase of temperature. The iron, remaining, is magnetic oxide.

Percy had an experiment tried upon a polished strip of iron confined in a glass tube with water under hydrogen for one year, and found it unaltered. The effect of air and water conjointly, is rust, which is the hyd. sesquioxide of iron. The presence of minute foreign matter in the air, as sulphuretted hydrogen, chlorine, hydrochloric and acetic acids, induces rusting in moist air. But the presence of CO^2 and HN^4 are attended by no results.

It is said that rust contains ammonia, which may be formed during the rusting, by absorption from the air.

When iron is submerged under water, which itself is exposed to the atmosphere, it is gradually converted to the black hydrated magnetic oxide, because of the traversing of the air through the water to the iron, as is supposed by Wöhler.

Aqueous solutions of potash, soda, and ammonia have been found, when not too dilute, to preserve iron from rust.

Payen says one part of saturated solution of potash to two thousand parts, by measure, of water, is sufficient, and the same of soda, to any number under fifty-four of water. The bicarbonate of the alkali loses the power. Hall says water containing not more than one-fifth volume of lime, preserves iron from rusting.

Zinc in contact with iron protects it from rust, and tin promotes rust.

Common rosin melted with a little Gallipoli oil, and spirits of turpentine, is a better protective covering than fats and oils. (Percy.)

At a red heat, or higher temperature, iron decomposes water. Hydrogen is evolved, and fine octahedral crystals have been formed when the iron was under very high temperature, and the steam current not too strong, but carefully regulated.

Iron and Sulphur.

Iron has a strong affinity for sulphur. Combination takes place at a red heat. Experiment: A bar, heated white hot, combines rapidly with sulphur, evolving light and melts into drops of sulphide. There are several definite sulphides of iron.

Lowest sulphide is said to be Fe^8S . A blackish-gray powder with metallic gray streak 6.67 per cent. S. The gas evolved contains seven volumes hydrogen to one of sulphuretted hydrogen. Disulphide iron Fe^2S . Resembles the last, and is strongly attracted by the magnet; it evolves hydrogen and sulphuretted hydrogen in equal volumes.

Protosulphide of Iron.

Formed by heating together sulphur and iron. May be formed on a large scale by heating scrap wrought iron red hot in a crucible, and dropping sulphur into it, at intervals, keeping the crucible covered. Apt to contain an excess of iron, hence care should be taken to conduct the process at a temperature below the melting point of the sulphide; otherwise the metallic iron will evolve hydrogen and HS with dilute acid.

Protosulphide of iron is precipitated as a black, amorphous, flocculent substance, by addition of sulphide of ammonium to neutral aqueous solutions of protosalts of iron. It is not redissolved, but a greenish solution remains which, after a time, precipitates a substance like that above mentioned, and the green disappears. Thus, in preparation of ultramarine, a mixture of kaolin, carbonate of soda, and sulphur is heated and washed on a filter; a deep-green bright solution passes through, which soon after acquires a brownish-yellow color, characteristic of a solution of an alkaline sulphide containing more sulphur than a monosulphide. It is supposed by H. Rose to contain an amount of sulphur greater than does the protosulphide. This may some day explain the presence of minutely divided gold in some iron pyrites, which is supposed to have been deposited from solution; the sulphide of gold acting as a sulphur acid forming sulphur salts with alkaline sulphides.

It is not known, Percy thinks, that precipitated protosulphide is a hydrate. The same variety of sulphide is formed when the so-called artificial volcanoes of Lemery are made by burying a mixture, in large quantity, of iron filings, sulphur, and water, at a slight depth below the surface of the ground. Moistened with water the mass absorbs oxygen rapidly, and sometimes, when the mass is large, may develop so much heat as to inflame.

When heated and exposed to hydrogen at a high temperature, it is not decomposed.

Protosulphide of iron *exposed to action of vapor of water at a very high temperature.*—Heated to redness in

a current of steam it is decomposed, hydrogen and sulphuretted hydrogen in large quantities are disengaged, and a black substance remains which is attracted by magnet. Regnault found that, in passing hydrogen over it in a glass tube for three hours, only one-half sulphur was removed.

The hydrogen is formed by decomposition of the water in the formation of the protoxide of iron in the early stage of this process.

Protosulphide of iron *heated with carbon*.—Heated very strongly with charcoal it parts with a portion of sulphur, which escapes, probably, as bisulphide.

In some experiments by Percy it seemed that all silica gravitated to the bottom, and the button formed only after strongly heating (in a crucible, brasqued) to whiteness for about two and a half hours, 250 grains being the amount of protosulphide used.

Protosulphide of iron *heated with sesquioxide of iron*.—There is no separation of metallic iron even when heated to high temperature in any proportions.

Protosulphide of iron *heated with sulphate of protoxide, or of the sesquioxide of iron*.—It is decomposed, sulphurous acid being copiously evolved, and if the mixture be in proper proportion neither sulphur nor sulphuric acid will be found in the residue.

Berthier says that the result is reached by gradually heating to whiteness 2.4 grammes protosulphide with 13.2 grammes of anhydrous bisulphate of sesquioxide, that is in ratio of 1 : 3 equivalents.

Protosulphide of iron *heated with lead*.—No definite results.

Protosulphide of iron *heated with carbonate of potash or soda*.—At red heat, with once or twice its weight of carbonate of potash or soda, forms a very liquid product, solidifies on cooling to a homogeneous crystalline black and very magnetic mass. Dissolved in water, some alkaline sulphide with little excess of sulphur, but no sulphate, dissolves.

When the mass is melted with charcoal, metallic iron is separated, which at sufficiently high temperature fuses

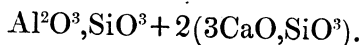
into a lump and is easily detached from the slag. The mixture heated in a brasqued crucible yielded a button of white crystalline iron, which flattens sensibly under the hammer; more than four-fifths of the iron of the protosulphide is contained in the button. The slag was black, lamellar, slight bronzy tint.

Protosulphide of iron *heated in admixture with charcoal and baryta, or lime.*—Is in great measure reduced by it, and as the double sulphide formed is difficult of fusion the iron is finely disseminated.

Protosulphide of iron *heated with other sulphides.*—This has been done, and union seems to be perfect between it and the sulphides of barium, calcium, as well as of various other metallic sulphides, but nothing has been otherwise definitely arrived at.

Protosulphide of iron *heated with silica and carbon.*—It is nearly completely decomposed at a high temperature by the joint action of these elements.

Protosulphide of iron *heated with alkaline silicates or borates.*—This is important in the smelting of iron. Berthier states, that if they contain a certain proportion of acid they have no effect upon the protosulphide, but the contrary is true if they contain excess of base and carbon is present. In this case part of the base unites with the sulphide of iron, and in amount proportionate to the elevation of temperature. This is true of basic silicate of lime, whether free or in combination with basic silicate of alumina. The desulphurizing action of basic silicate of lime is seen in the slags which sometimes emit sulphur when the silica is being only heated preparatory to weighing it. One common variety of such lime has the formula according to Percy, of



Hydrochloric acid decomposes it, and there is always the disengagement of sulphuretted hydrogen.

Protosulphide of iron *heated with silicates, or borates of manganese.*—Action similar to that of the preceding. Not much known as yet.

Mr. Parry, of the Ebbw (Eb'-boo) Vale Works, finds

considerable sulphur in slags which contained much manganese. Thus in the slag from spathic ore, the manganese estimated as protoxide amounted to 8 per cent., and the sulphur not less than 2 per cent.; whereas, with the same fuel, but with ores containing less manganese, the slag contained less sulphur, and the cast iron a proportionally larger amount of sulphur.

Sesquisulphide of Iron.

Thrown down as a black precipitate when a solution of sulphate of sesquioxide of iron is added drop by drop to a solution of a hydrosulphate, but not on pouring the latter into the former. It is formed in a slow way by passing a current of sulphuretted hydrogen over the sesquioxide heated to not more than 100° C. till water ceases to escape.

Bisulphide of iron, or iron pyrites FeS_2 (iron 46.7, sulphur 53.3 parts in 100).

Abounds in nature. Is dimorphous, crystallizing in the cubical and the prismatic systems (*i. e.*, as rectangular and right rhombic prisms, and rhombic octahedrons). Used much in the manufacture of sulphuric acid. Cubical iron pyrites has a fine brass color, and has been mistaken for gold. The prismatic variety is termed white iron pyrites from its grayish, or light greenish-yellow color. It is not so widely diffused as the yellow—it is the usual form found in coal and has a tendency to decompose and effloresce in the air, being changed into sulphate of *protoxide*, and after longer exposure and absorption of more oxygen into sulphate of peroxide. This latter, when in contact with organic matter excluded from the air, changes back again into pyrites, hence, probably, the origin of much of that substance in nature.

Both kinds of pyrites occur botryoidal and reniform, and also amorphous. It has been known, repeatedly, to be deposited in crystalline structure, around decaying matter, and a mouse accidentally fallen into a solution of sulphate of protoxide of iron and having lain there a considerable time, had crystals of bisulphide deposited

upon it. When subjected to red heat in close vessels, sulphur sublimes, and the residue is magnetic pyrites. Some sulphides, by exposure to low heat and moisture for a sufficiently long time may have been changed into hydrated hematite, as alluded to on page 60.

Magnetic pyrites. — 6FeSFeS^2 (sulphur 39.5; iron 60.5; Rose). Is feebly attracted by the magnet, and sometimes polaric, hence its name. It is rhombohedral; readily fusible; met with in nature sometimes nickeliforous, and frequently combined with copper. It is this which is formed by heating iron till it burns and touching it with a sulphur roll. It is largely associated with native gold west of the Mississippi. It occurs massive in fissures in the crystalline rocks, and is found sometimes with and in the vicinity of good magnetic iron ores, at a mile or more north of Fort Henry, Lake Champlain, and in Lewis and Orange Counties, New York.

Sulphate of the protoxide of iron, *copperas*, *green vitriol*.

Sulphate of the protoxide crystallizes with various proportions of water. The common salt crystallizes in the oblique prismatic system, and has the formula $\text{FeO},\text{SO}^3 + 7\text{HO}$, (36.40 + 63). At a gentle heat it melts in its own water of crystallization—above 280°C ., loses 6 equivalents of water; at a higher temperature becomes anhydrous, forming, in absence of air, a gritty powder (white), which dissolves slowly in water. Heated more strongly it is decomposed with evolution of sulphurous acid and production of sulphate of sesquioxide; at a higher temperature, all the sulphuric acid is expelled, and nothing but sesquioxide remains. The sulphuric acid of Nordhausen is distilled from this salt after 40 per cent. of water has been driven off.

When an aqueous solution of this, or othersalt of protoxide of iron, is put into a close vessel with zinc or cadmium, metallic iron is slowly reduced.

An aqueous solution of sulphate of protoxide of iron absorbs nitric oxide (NO^2) forming a dark greenish-brown liquid in which the gas and the sulphuric acid are in the ratio of 1 : 4 equivalents. Green vitriol is

produced by dissolving metallic iron in dilute sulphuric acid, filtering the boiling solution, evaporating and crystallizing. It is desirable that the solution should be acid. It is formed by the spontaneous oxidation of a sulphide of iron in moist air, or by roasting a sulphide at a low temperature with free access of air. It is found as an efflorescence in several places in the United States, at Copperas Mountain, a few miles east of Bainbridge, Ohio, and elsewhere. It occurs in the waters of old coal mines, and care should be taken not to use the water from such mines for boilers, as it corrodes the iron with rapidity. Its presence is recognized by its inky taste, or, better, by dropping a few drops of strong solution of common yellow prussiate of potash into a glass filled with the suspected water. Its blue color, deepening in shade as it stands, will determine the presence of the iron, and a little of the solution of chloride of barium will, by its white precipitate, prove the SO^3 . The salt is largely used in dyeing and in the manufacture of colcothar.

The impurities of the commercial salt may be manganese, zinc, copper, alumina, magnesia, lime, and more or less of sulphate of sesquioxide of iron; from the latter it may be purified by passing sulphuretted hydrogen through the solution, heating to expel the gas, and then separating the sulphur formed in the reduction of the sesquioxide: or, by simply boiling with metallic iron.

On the addition of sufficient alcohol it is thrown down as a greenish crystalline powder, which may be readily dried after washing with alcohol, and preserved without change in a stopped bottle; it contains seven equivalents of water, as usual, and 20.143 per cent. of iron. Percy has kept this for standardizing solutions for volumetric iron assay, for years without change. (See Index.) If there should be present any arsenious acid, both it and metallic copper may be removed by introducing metallic iron and by boiling. The grass, or yellowish-green appearance of the commercial salt is due to sulphate of sesquioxide.

There are not fewer than four hydrates besides this: one with one equivalent of water, a second with three

equivalents, a third with four equivalents, and yet another with six equivalents. (Graham, Ph. Tr. Ed. xii. 297.)

Neutral Tersulphate, or Sulphate of Sesquioxide of Iron. $\text{Fe}_2\text{O}_3, 3\text{SO}_3$.

It was observed at the sulphuric acid works at Oker, in the Hartz, in pouring out the concentrated sulphuric acid from the platinum still, as shining particles which subsided. They are minute, pale peach-colored crystals, in truncated rhombic octahedra; nearly insoluble in water, and not much more soluble in hydrochloric acid, but instantly decomposed in ammonia, with separation of hydrated sesquioxide of iron.

It occurs near Copiapó, in Coquimbo, forming a bed in feldspathic rock, and near Calama, in Bolivia. It is massive or crystallized in rhombohedral system, and has the formula as above + 9 HO.

May be made by boiling two equivalents of sulphate of protoxide of iron with one of sulphuric acid, and adding nitric acid in small quantities until gas ceases to evolve. It dissolves in water, yielding a red solution, which, on evaporation, yields a pale yellow deliquescent residue. It is a powerful styptic.

Sulphides of Iron Roasted in the Air.

Reactions are substantially the same with all the sulphides. Some remarks should be added respecting two sulphides:—

The Protosulphide.—Heated to dull redness sulphurous acid is disengaged. The amount of heat determines greatly the nature of the product. At a low temperature much sulphate of the protoxide of iron results, which acts, on increasing the heat, as does that salt. Magnetic oxide is produced in all processes of roasting, in practice.

Bisulphide.—In roasting this, there is direct combustion of the sulphur; otherwise, it is as with other sulphides, except that under certain temperatures at the early stage there results much magnetic sulphide.

Iron and Nitrogen.

Nitrogen is supposed to play an important part in the manufacture of steel, and some suppose that it is an essential element.

The heating of nitrogenous matters, as leather parings, horn, ferrocyanide of potassium, &c., with iron has long been known as a method of *case-hardening*. Recently the subject has attracted the attention of chemists, and many careful and varied examinations of iron, steel, and cast iron for nitrogen have been made, and the general results may be summed up thus:—

1st. Nitrogen does combine with iron.

2d. That its presence has been detected in malleable iron, steel and cast iron.

3d. That when in sensible proportion in iron it modifies the iron in a remarkable manner.

Iron wire, according to Buff, from experiments in Liebig's laboratory, heated to redness in a current of ammoniacal gas, becomes brittle, crystalline and white, and increases 6 per cent. in weight, while the specific gravity was reduced from 7.416 to 7.145. On burning it with soda-lime, ammonia (NH^4) was formed. In a specimen of cast iron, smelted from bog ore, he found 0.26 per cent. nitrogen. It is easy to trace the source of nitrogen discernible in cast iron, when we remember the large amount set free in the blast furnace, from the atmosphere when the oxygen of the air is consumed in the process of making iron.

Iron and Phosphorus.

They do not combine at ordinary temperature, but in contact with red-hot iron, phosphorus will combine with incandescence.

A phosphide of this formula Fe^{12}P . Dropping phosphorus upon red-hot iron filings, or wire, in a crucible, will, with air excluded, produce a phosphide containing about 8 per cent. phosphorus. A button formed of this phosphide, and left to cool in the crucible, shows long

interlacing crystals externally and internally beautiful, brilliant, iridescent prismatic crystals where cavernous. External color, blue.

There are no less than six other phosphides.

Phosphorus, even in very small quantities, has a decided effect upon the malleability and strength of iron at ordinary temperature, causing cold-shortness, that is, tendency to break "short off" when cold. And while this fact is true at ordinary temperature, there may be no effect produced upon the same iron at a high temperature when hammered, or rolled. This is an established fact.

Karsten thought that iron was not materially affected when the phosphorus was not more than 0.5 per cent., and up to 0.3 it only hardened without diminishing the tenacity, which seems to be corroborated by the fact stated, p. 61, as to the endurance of car-wheels cast of iron containing phosphorus. But, when containing 0.6 it will not stand the breaking test, yet stands the test of bending at right angles, over the anvil; and with 0.66 it does not show plainly the cold-shortness, properly so called. As soon as it reaches 0.75 per cent. the decrease of tenacity is notable, and the iron no longer stands the tests above referred to. With 0.8 per cent. it is decidedly cold-short, and with 1 per cent. it can no longer be bent at right angles. With more than 1 per cent. it is extraordinarily cold-short, and can be applied to few purposes.

Experiment: Iron wire heated with a phosphide sufficient to produce 1 per cent. makes a button of singular crystalline structure.

Phosphide of iron was once, before the year 1784, considered a new metal and called "Siderum," and was first noticed in cast iron smelted from the bog iron ores. By dissolving such cast iron in dilute sulphuric acid, a white precipitate was deposited, and by heating it *per se* in a crucible made out of a solid piece of charcoal, a beautiful button was made, in the interior prismatic crystals were formed, and the metal was not attractable by the magnet. It was phosphide of iron.

Fluoride of calcium (fluorspar), on iron containing phosphorus. Effect, none, or very slight, in a brasqued crucible.

Action of *carbon on iron* containing phosphorus. Has a tendency, very decided, to deprive the iron of phosphorus.

Tribasic phosphate of protoxide of iron: $3\text{FeO}, \text{PO}^5$. Berzelius says it may be formed by pouring a solution of phosphate of soda, drop by drop, into a solution of a salt of protoxide of iron. At first it is cheesy white—becomes semi-transparent and gelatinous. When collected on a filter it begins instantly to turn green, or blue, by absorbing oxygen.

The blue mineral called *vivianite* is a pseudomorph of this salt. Occurs crystallized as well as earthy. The following is the composition of two specimens of the New Jersey vivianite from Mullica Hill: $\text{PO}^5 28.40$, $\text{Fe}^2\text{O}^3 12.06$, $\text{FeO} 33.91$, HO not determined, sp. gr. 2.58; Rammelsburg, $\text{PO}^5 26.06$, $\text{FeO} 46.31$, $\text{HO} 27.14 = 99.51$; Thompson. It is often associated with bog ore, as at Allentown, Monmouth County, New Jersey; Virginia, Stafford County, and 8 or 10 miles from Falmouth. When such specimens are found it may readily be understood why the neighboring beds of ore may be suspected of containing phosphorus.

Action of iron, at high temperature, upon *phosphate of lime*, in the presence of carbon: Phosphate of lime imparts its phosphorus to the iron whether the phosphorus be in the lime, used as a flux, or in the ore which produces the iron. It appears also in the slag, but from some experiments at Aberdare Iron Works, it seems that, if the heated contact had continued long enough, all the phosphoric acid would have combined with the iron.

Manganese and Phosphorus.

Manganese has but little influence upon phosphorus to separate it from iron.

Iron and Arsenic.

There are several arsenides of iron. That of the formula FeAs , or properly arsenide of iron, occurs native. Heated to redness in close vessel, metallic arsenic is sublimed. Roasted in the air arsenious acid is copiously evolved and basic arseniate of sesquioxide of iron is left.

The arsenide of formula Fe^4As is formed by mixture of iron wire in small pieces, and an excess of arsenic, fused under a glass flux in covered clay crucibles.

Pieces of hoop iron, heated nearly to whiteness in a clay crucible, and excess of arsenic dropped in, causes immediate combination with bright incandescence, and the iron melts completely.

Arseniate of sesquioxide of iron. This is the nature of the crystallized mineral *scorodite*, having formula of $\text{Fe}^2\text{O}^3, \text{AsO}^5, +4\text{HO}$. Heated to incipient redness it suddenly becomes incandescent.

The same with $+12\text{HO}$: has been found near Freiburg and known as *eisensinter*, and the mineral *cube ore* is a basic arseniate with $+15\text{HO}$, according to Ramelsburg. The mineral has a fine green color.

Arsenic may be completely extracted from iron by deflagrating the powdered metal with nitre (saltpetre) and carbonate of soda in a gold crucible. On washing the residue pure alkaline arsenic is removed and pure sesquioxide of iron remains. So arsenic, or arsenic acid may be entirely removed from any salt of iron by fusion with fixed alkaline carbonate in a platinum crucible. Arsenic may be perfectly precipitated as *ammonia-magnesian arseniate*. Dissolve the salt in hydrochloric acid, peroxydize,* treat with tartaric acid, then with excess of ammonia and a solution of a salt of magnesia previously mixed with sufficient ammoniacal salt to prevent the precipitation of magnesia by ammonia. The whole of the arsenic is precipitated after a while in beautiful crystals of magnesian salt. Collect on a filter; wash with water strongly impregnated with ammonia; dry at

* By adding NO^5 or boiling once with little chlorate of potash.

C. 100° ; weigh. It has, thus dried, a formula 2MgO , NH^4O , $\text{AsO}^5 + \text{HO}$, and contains 60.53 per cent. arsenic acid and 21.05 per cent. magnesia. If the salt is heated rapidly to redness it loses water and ammonia, and the latter reduces the arsenic acid and causes loss.

A ready way of determining the presence of arsenic in arsenical iron is by heating some six or eight grains of the powdered ore by throwing it upon a burning coal. The fumes smell strongly of garlic, the certain sign of arsenic in the ore. One slight snuff of these fumes is not hazardous, though it is not advisable to repeat the experiment more than once or twice, unless cautiously as to quantity inhaled.

Arsenical iron, called *mispickel*, is frequently mistaken by miners and others for silver. It has a silver-white color inclining to steel-gray, especially when first broken; sp. gr. 6 to 6.26, streak or powder dark grayish-black, and it is brittle. These characteristics may serve to distinguish it from native silver, as the latter is sectile easily by the penknife and never brittle, has a sp. gr. of 10 to 11, and when heated on charcoal with the blow-pipe gives out no fumes. Some years ago a so-called silver mine was discovered near the Great Meadows, fifteen miles northeast of Belvidere, N. J., in the high hills northwest of Danville, and many bought stock. After the abandonment of the mine we examined the drift run into the hill and, from the debris, discovered that considerable quantities of mispickel had been taken out. A large amount of money was invested and lost in that mine. We mention this because similar mistakes are frequently made at the present, and the above tests are sufficient to detect the error.

There are no ores of iron containing arsenic which are used as commercial ores. Arsenic, however, in proportions from 9 to 27 per cent. is said to cause iron to be very brittle, white, and of a brilliant radiated structure, and unfit for conversion into malleable iron by the puddling process, as it occasions red-shortness although sufficiently tenacious to bear hammering when cold. In smaller proportions it is said to be beneficial in iron

intended for chill casting, *i. e.*, surface hardening by casting in cold metal moulds.* The above proportions were found in some cast-iron shot and shell of Turkish origin, those brought from Sinope containing 16.2 per cent., and of those found in the arsenal at Algiers in 1830, the shot contained 27 per cent., and the shell 9 per cent., the former being very hard but brittle.

Mispickel contains arsenic 46.00, sulphur 19.6, iron 34.4 = 100 parts.

Case Hardening Iron, or Steel by Arsenic.

In Sweden rasped leather, horn, or other nitrogenous animal matter is mixed with a solution of arsenious acid dissolved in hydrochloric acid to the consistency of common paste. The metal (files, &c.) is painted over, to the thickness of $\frac{1}{16}$ in., with this mixture and heated in a muffle, or iron cylinder to bright redness. A white surface of arsenide of iron of great hardness is thus produced. Ekman, of Gothenberg, Sweden, assured Percy that it protected the iron from rust, on an experiment of fifteen years. Percy tried the experiment, heating the iron in charcoal and alkaline arsenide of iron to redness—though the iron was hardened it rusted.

Silicon.

It is very important to study the action of silicon upon iron. Our knowledge is yet imperfect.

It is a constant constituent of cast iron, and its oxide, silica, forms an important part in the formation of slags, accompanying the metal both in its reduction from the ore and in its subsequent conversion into wrought iron.

Reduction of Silica by Carbon, in the Presence of Oxide of Iron and other Bases.

It appears to be established that free silica unaccompanied with earthy matter with which it might combine

* Bauerman.

to form slags, such as carbonate of lime and clay, tends to produce iron rich in silicon, especially under high temperature and presence of much carbon.

Experiment 1 (in Percy's laboratory). Take red hematite containing 69 per cent. iron, expose in intimate mixture with fine sand and charcoal in covered crucible to high temperature. Product, a fritted mass with disseminated globules; separate by magnet as clear from slag as possible and remelt with a little magnesia and alumina. Well melted buttons obtained, easily detached from slag.

Metal hard and brilliant, fracture light gray, highly crystalline, faces at all angles.

Experiment 2. A compact red hematite was taken containing much finely diffused quartz. Hydrochloric acid was used in dissolving this ore, leaving 13.49 per cent. insoluble matter, of which 12.76 per cent. was silica; it yielded (with charcoal enough simply to reduce) an iron containing 0.87 per cent. of silica.

The same ore, heated in admixture with considerable charcoal in excess, yielded metal with 13.78 per cent. silicon. In both experiments the crucibles were heated to very high temperature.

In another experiment this ore was heated with charcoal and sand in excess, and the button contained 8.84 per cent. silicon.

In each experiment 1000 grains of ore was used.

Charcoal 250; lime 100; fluor spar 250; produce 1.41 per cent. silicon.

Charcoal 250; fluor spar 150; produce 2.15 per cent. silicon.

Charcoal 250; lime 400; clay 190; sand 110.

Calculated composition of slag:

Lime 51; alumina 10; silicon 39.

Silicon 0.64 per cent.

Charcoal 250; lime 300; clay 190; sand 190.

Calculated composition of slag,

Lime 52.4; alumina 13.3; silicon 34.3.

Metal contained 0.58 per cent. silicon.

This slag approximates ordinary "blast furnace cinders," that is from iron smelting furnaces of England.

Charcoal 350; lime 125; clay 190; sand 260.

Metal, white iron 0.85 silicon.

Reduction not complete.

Charcoal 250; lime 125; clay 190; sand 260.

Calculated slag:

Lime 19; alumina 11.5; silica 69.5.

0.38 silicon.

Charcoal 250; lime 125; clay 190; sand 400.

Additional charcoal was placed on the top of the mixture; slag, green. Metal contains 1.15 per cent. silicon.

Pig iron containing 3 per cent. silicon has invariably a smooth face, whereas cold blast-iron containing 1 to 2 per cent. silicon has a "honey-combed face." (Parry.)

Protoxide of Iron and Silica.—Protoxide of iron and silica readily combine at high temperature, hence earthen crucibles cannot be used in the laboratory; wrought iron must take their place.

<i>Experiment.</i>		Grains.	Ratio of mixture to yield 100 of silicate.
	Hematite	2400	78.1
	Silica	900	29.8
	Anthracite	180	6.0

Product very liquid, easily poured out, weight 3070 grains, showing excess of 70 grains due to the iron derived from the crucible (of wrought iron).

Silicate of Protoxide of Iron reduced by Carbon.—Clay crucibles, brasqued with mixture of charcoal powder and treacle, are employed; "tap cinder" from a puddling furnace is operated upon; this cinder by wet assay yielded 55.19 per cent. iron, slightly exceeding $3\text{FeO}, \text{SiO}^3$; 10 grains of the powder of this slag were taken, intimately mixed with two of charcoal, exposed in a luted crucible previously brasqued, it was subjected one hour to strong heat. Product: well melted buttons of white iron; usually this tap cinder contains phosphorus, and the iron should be rich in phosphorus.

Tribasic silicate of protoxide of iron heated with access of air. When the powder is roasted it passes more

or less into the sesquioxide, and when, in lumps as large as the fist, it is thus heated, as when the tap cinders for puddling furnace are heated in kilns (similar to brick kilns) for days, it becomes the refractory substance called "bull dog." A patent was once taken out for this method of rendering the cinder refractory. The refractory nature is due to the formation of sesquioxide.

Iron and Carbon.

This is the most important compound. Under the name of iron are included metals differing more in physical properties than do some metals which are chemically distinct. This difference in iron is chiefly due to carbon.

When carbon is absent, or present only in minute quantities we have *wrought iron*, which is soft, malleable, very tenacious, but difficult to melt in any ordinary iron furnaces, and not susceptible of tempering.

When carbon is present in certain higher proportions, the limits of which cannot be exactly set, we have *steel*, and which is malleable as is wrought iron, but, unlike that, it is fusible and capable of tempering to such hardness as to cut wrought iron. With more carbon we have cast iron which is hard, brittle, readily fusible, but is not weldable, or forgeable. The difference is generally and essentially due to differences of carbon, although other elements enter in to improve and otherwise modify the iron.

The essential condition of the combination of iron and carbon is, that carbon, or certain gaseous compounds of carbon, come in contact with the iron at or above a red heat.

When an oxide of iron is reduced with an excess of carbon, at, or above the melting point of cast iron, combination takes place rapidly and cast iron results, and, all other things being alike, the higher the temperature the more readily does this take place.

Combination takes place more slowly when iron, in the compact state, as in a bar, is exposed imbedded in carbon to a heat equal to, or above that of red heat. Thus

steel is made extensively in England and America, and the process is called *cementation*. The heat is said to be about that of melting copper (about 2000° Fah.) A gaseous hydrocarbon can be, and has been, used in place of charcoal. The cause of this change of iron into steel has exercised philosophic attention extensively, but it is not yet fully understood.

Percy tried a large number of experiments, from which we gather:—

1. That carbonic oxide, passed over heated iron, produces steel and increases the weight.

2. Solid carbon, in the presence of carbonic oxide, produces steel.

3. Solid carbon, in the presence of hydrogen, produces steel of an inferior condition: it could only be hardened by being plunged, red hot, into mercury. Hydrogen, *per se*, seemed to have no effect in hardening the iron.

4. When iron wire is kept red hot, only one hour, in coal gas, it hardens like steel.

5. Vapor of paraffine may be substituted for coal gas. This was done with an iron wire in a porcelain tube heated to whiteness during one hour, and steel was formed.

A matter of much interest results from some experiments of Percy, as follows:—

Two slips of iron wire were placed in a porcelain tube, one imbedded in charcoal made from sugar—the other not imbedded. A current of hydrogen was slowly passed over the two pieces, from B to A.

Fig. 14.



B was imbedded, A not. B was steeled, and so was A. This was so when the charcoal had been so intensely heated that it would no longer, by itself, carburize a piece of wire, and yet, when the same apparently decarburized charcoal was put at B and hydrogen passed over it at a red heat, A was carburized. The question arises, was it

from the hydrogen mechanically taking up carbon, or was it from hydrogen eliminating, by some chemical affinity, the, so to speak, latent carbon of the charcoal, and thus charged with carbon, passing over to the piece A, and carburizing it? When the position of the pieces A B were reversed so that hydrogen had to pass A uncovered, before it struck B which *was* covered, then A was not altered to steel. How the carburization takes place by simple contact of carbon, is a mystery, although the red-hot condition of the iron may give mobility to the atoms which may change position, or, by induction of a nature not understood, yet conceivable, may impart from layer to layer, from without inward, that carburizing condition which all those acquainted with the theory of the atomic change undergone by water in the galvanic cell, may easily understand. At any rate, the whole bar is completely carburized into steel by, what we shall hereafter explain as, *cementation*.

Carbon may be extracted, as well as introduced, by *cementation*. Thus, cast iron, heated red hot for days, in contact with powdered red hematite, becomes deprived of a part of its carbon, and is thus reduced to an iron of the comparatively soft or malleable condition of "malleable iron." In England, as in this country, various small articles, made from cast iron smelted from red hematite with charcoal, are thus treated, and the condition of the iron before, and after heating, may be understood better by the following analyses by Dr. W. A. Miller, of Cambridge:—

	Before.		After.
Specific gravity	7.684		7.718
	In 100 parts.		
Carbon { Combined 2.217 } = 2.800		{ 0.434 }	= 0.880
{ Uncombined 0.583 }		{ 0.446 }	
Silicon	0.951		0.409
Aluminum	trace		trace
Sulphur	0.015		0.000
Phosphorus	trace		trace
Sand	0.502		

Hence four-fifths of the combined carbon seemed to have been removed, and all the sulphur; which last fact

is remarkable. The silicon removal also seems unaccountable, though it was asserted as accurate.

Carbon may be removed by keeping iron in thin plates at a red heat exposed to a current of atmosphere. A process of this kind has been adopted in England.

Amount of Carbon in Iron.—Karsten says that the maximum of carbon with which iron will combine is 5.93 per cent.; definite carbides he has not succeeded in forming.

Pure iron, he says, is so soft that it offers little resistance to friction.

With 0.2 or .25 per cent. carbon it becomes steel, and will harden by sudden cooling after heating. The freer iron is from foreign ingredients, as silicon, sulphur, and phosphorus, the more carbon is required to induce hardening by this process (of tempering).

In the best Swedish bar iron, as well as in the German iron made from spathic ore and from brown ore, 0.35 per cent. carbon makes the iron steely. The point of passage from iron into steel is an impalpable one. When foreign matters are present .5 of carbon is sufficient to make steel which will give sparks with flint. But, when the iron is perfectly free from foreign matters, 0.65 per cent. is necessary to effect the same degree of hardness. Iron with 1 per cent. to 1.5 per cent. is steel, with the maximum tenacity combined with the maximum hardness.

When higher quantities of carbon are added, hardness increases to the sacrifice of tenacity and weldability. With 1.75 the last property, weldability, almost entirely disappears. With 1.8 it may be worked; but with utmost difficulty. When 1.9 is reached, the iron ceases to be malleable while hot, and 2 per cent. is the limit between steel and cast iron; it cannot then be drawn out nor worked.

Of cast iron there are two kinds—gray and white.

They differ as follows:—

Gray iron has a higher melting point than white, and passes almost instantly from the solid to the liquid point, when it becomes very liquid.

White iron becomes soft and pasty before it becomes

liquid, and at a lower temperature. Karsten says that gray iron, by rapid solidification after fusion, becomes white; and white, by very slow solidification after fusion, becomes gray, without any change of the proportion of carbon in either. It was sought to account for this, in the different modes of existence of carbon in these two irons. In white it was supposed wholly combined; in gray it was partly combined and partly in the state of graphite. Iron containing 2 per cent. of carbon (making it equal to steel), when cooled down, after fusion, with the slowest possible solidification, retained its carbon; but when 2.3 per cent. were present in combination, graphite was formed, and the metal appeared like cast iron. Beyond this limit, up to 5.93 per cent., the iron of white iron is the hardest and the whitest.

Percy thinks that iron cannot contain so much carbon, but various analyses seem to sustain Karsten in his above-quoted remarks.

Experiments by Sefström.—Wire was put into a carbon crucible, covered with carbonate of lime, and heated in a blast furnace one and a quarter hour; a well-melted button of cast iron was obtained; fracture gray and polished; increased weight 4.34 per cent.

Experiment 2.—Wire was heated upon lime, and covered with charcoal; it melted and increased 3 per cent.; the fracture had an unusual aspect, presenting a thin, velvety, dark border, very crystalline, with facets extending almost across the button, hard as slightly hardened steel. This experiment varied in point of crystallization. No difference in the results when carbonate of lime was used, or caustic lime.

In Percy's laboratory the following *experiment* was tried:—

Anhydrous sesquioxide artificially prepared, free from sulphur, but not entirely free from silicon, was employed; 500 grains intimately mixed with 100 grains Ceylon graphite, containing $1\frac{1}{2}$ or 2 per cent. earthy impurity. The mixture was put into a plumbago crucible, and the space above well filled with pressed-down plumbago. Exposed to comparatively low temperature eight hours,

rapidly cooled; a button was obtained, well melted, weighing 347.5 grains. On the top were brilliant scales of graphite, which seemed to have been separated from the iron; fracture dark gray, with spots of graphitic lustre.

Contained 19.35 per cent. iron,
4.63 “ graphite.

To determine the combined carbon, dissolve the metal in hydrochloric acid; evolution of fetid hydrogen may take place, boil the residue in solution of caustic potash. If carbon is *combined*, the solution will become brown, and on neutralizing it with hydrochloric, or other acids, flocks of carbonaceous matter will precipitate; if *no combined* carbon exists, the above results will not occur, and the potash solution will remain clear. Graphitic carbon remains undissolved if present, and may be filtered off.

Modes of Existence of Carbon in Iron.—It is supposed to exist in a *combined*, and in an *uncombined* condition disseminated as graphite.

Graphitic carbon is supposed to separate, on solidification, after fusion.

When graphitic iron is melted, the graphite does not rise, as might be expected, reasoning from its lightness, but is redissolved, or disseminated through the mass.

When iron contains much graphitic iron its fracture is dark gray, granular, or scaly-crystalline, and it is then called gray iron.

When it contains much combined carbon, its fracture is white, more or less granular, or crystalline, and sometimes largely so; it is then *white iron*.

Gray passes by imperceptible gradations into white iron; but there is an intermediate state which may occur when the iron is mottled, and is then called mottled iron, and by the French *fonte truitée*, or trout iron. From the extreme of gray, to that of white, not less than eight grades are recognized in England, and Percy says that workmen will distinguish them all by the eye. Mottled iron begins at No. 5. In the United States, on the Lehigh, Pa., in Ironton, Ohio, and in New York, the grades are

generally foundry No. 1, No. 2, gray forge, mottled, and white iron; but these are again somewhat altered in other places, and even subdivided in the same places, into No. 1 x, No. 1, No. 2, No. 3, then a mottled; the classes, or kinds, are not always determined by the whiteness, or openness of the iron, but by their character otherwise, as gray forge neutral, gray forge red-short, &c., so that as many grades exist in the iron market in our country as in England. There may be combined carbon in gray iron, and yet the white iron not distinguishable by the eye. Conversely, white iron may contain some graphitic iron which may not be seen. Some gray iron may have some combined carbon; but, nevertheless, white iron may be entirely free from graphitic carbon. The mode of existence of carbon in iron is, to a great degree, determined by the conditions of solidification of the iron after fusion, and the amount of heat to which it has been subjected.

Rapid solidification favors the retention of carbon in the combined state, and by this means it is possible to change gray into white. Thus by pouring liquid gray into a mould, so that the outside of the iron is chilled suddenly, it becomes white and as hard as white iron always is, while the internal part remains gray; this is the principle of *chill-casting*. Not all gray can be thus converted into white, as Percy says, having had some iron tapped at a furnace upon metallic plates, and some into a hole in sand. The plate, though cooled suddenly, remained gray, though only $\frac{1}{8}$ in. diameter; but this may have been because the melted iron was possessed of more than its usual carbon, and would not therefore disprove the rule that such chilling will always change a certain amount of uncombined, or graphitic carbon, into combined carbon, when the iron is not too highly carbonized, and the iron not too highly heated to allow a certain amount of chilling to cause all the surface-carbon to combine. It only becomes a matter of judgment and skill. Iron reduced by charcoal and cold blast always chills more deeply than other irons. Hence, always preferred for chilled car wheels in the United States.

The mode of existence of carbon in iron is also deter-

mined by the conditions under which the solid metal is heated at a temperature much below the point of fusion. Thus a steel bar, *cold*, yields no graphite by solution in acids; while the same bar, *annealed*, yields, while thus in a softened state, a sensible amount of graphite.

Caron found that *rolled* steels yielded a larger amount of carbonaceous matter than *hammered* steels. This he mentions in connection with the statement that it is known that rolling renders less service than hammering in the improved manufacture of steels.

Caron also found that the effects of heat were, sensibly, the reverse of the effects of hammering and hardening. Thus, steels annealed during various times, from hours to days, showed that the longer they were annealed, the more carbonaceous matter they exhibited. However long the annealing process was continued, a little carbon was retained combined.

The Chemical Combinations of Carbon.—Spiegeleisen, or specular cast iron, is largely crystalline, as the name intimates. Numerous analyses show carbonate 5 per cent. and wholly, or greatly combined. This corresponds to Fe^{C} . Hence this is regarded as a definite compound, but as manganese is always present, it is considered doubtful whether it is fairly a definite compound. A typical example of this variety of iron is presented by Schafhäutl:—

Iron	.	.	.	.	.	.	.	88.961
Carbon	.	.	.	.	.	.	.	5.440
Manganese	.	.	.	.	.	.	.	4.003
Silicon	.	.	.	.	.	.	.	0.179
Nitrogen	.	.	.	.	.	.	.	1.200
Copper	.	.	.	.	.	.	.	0.166
Tin	.	.	.	.	.	.	.	0.116
								<hr/>
								100.065

It varies, however, in the amount of both the carbon and the manganese. Percy states, on an analysis by Mr. T. H. Henry, that the spiegeleisen, made from franklinite, contained as high as 11.50 per cent. manganese, and not less than 6.90 carbon. The solid compound consid-

ered as Fe^4C seems, therefore, to be considered by Percy as $(\text{FeMn})^4\text{C}$. He found no change upon melting spiegeleisen under plate glass to a heat sufficient to melt wrought iron; although Gurlt states that white iron, by being heated much higher than its fusion point, may be converted to gray, causing a separation of carbon into graphite; and this he says of specular cast iron. Percy says he tried the latter without any such results. Karsten supposes that temperature has much to do, indeed, everything to do, with the mode of existence of carbon; thus if the white iron has been melted at a point of fusion much higher than necessary to fuse the metal, and then made to cool with the utmost slowness, it changes in accordance with the original temperature, to gray, mottled or white, and this may account for the failure of Percy in chilling, as heretofore stated, p. 118.

If the temperature at which it was, as white iron, kept heated a considerable time before allowing to solidify, was high enough, and the solidification carefully slow, it will be gray iron, if not high enough, only soft gray iron, etc., according to original heat. Percy doubts this in some degree. This is a practical subject of inquiry to the iron-master, for a high temperature seems to be necessary for graphitic iron, and slow solidification seems necessary for the separation of graphitic carbon in laminae.

When gray cast iron is heated far above its melting point and poured into a mould made of a bad conductor of heat, the fractured surface presents no great difference in appearance. But yet the internal part contains more graphitic carbon than the external, and it is so in chill-castings. These general truths are well established.

Action of Sulphur upon Iron containing Carbon.—Karsten says sulphur expels carbon from iron at a high temperature. When iron containing the maximum of carbon, that is spiegeleisen, is melted with sulphur in a covered clay crucible, carbon separates and collects on the under surface of the resulting sulphide of iron, and is considered as a dull variety of graphite. When iron is molten and cast upon sulphur not sufficient to make a sulphide

of all the iron, under the sulphide of iron will be the residual iron richer than before in carbon. The carbon is in the combined state, according to Percy, and he starts the question whether sulphur may not cause carbon to assume and remain in the combined state. Manganese (metallic) by simple fusion with cast iron deprives the latter, in great measure, of its sulphur.

By simple fusion in a crucible, with access of air, manganese abstracted from iron more than 0.7 of the sulphur which it contained.

In favor of this theory Caron asserts, that certain iron ores, impregnated with copper pyrites, yield pig iron free from sulphur, because they are highly manganiferous. They are, however, calcined before smelting. With this, note what Mr. Parry says that he had remarked that spathic ores caused slags containing manganese and sulphur, whereas other ores caused the iron to contain much sulphur and the slags little.

On the Action of Phosphorus on Iron containing Carbon and Sulphur.

Janoyer asserts, from experiments, that phosphorus expels a portion of the sulphur from iron containing carbon.

He thinks that the introduction of ores into the blast furnace, containing a sensible amount of phosphorus, may tend to counteract red-shortness due to sulphur. He records the results of his experience, that by the addition of Oölitic ore containing not more than 0.2 per cent. of phosphoric acid in the proportion of 0.106 of phosphorus to 240.0 of pig iron made, he obtained pig iron, which made bar iron practically free from red-shortness, whereas, without this addition, the pig iron, though produced from a fine quality of red hematite, free both from sulphur and phosphorus, always yielded red-short bar iron. The experiments seem to have been conducted correctly in every way, except that, in the one case, phosphoric ore was used in quantities not enough to produce cold-shortness, and, in the other case, no phos-

phoric ore was used. He made other experiments which proved that phosphorus does not expel sulphur from iron in the presence of sulphur alone.

Caron ascertained that manganese had no power to eliminate phosphorus from iron, as it has to eliminate sulphur.

Spiegeleisen heated with Silica.

From experiments in Percy's laboratory, it seems that 1500 grains in powder of spiegeleisen (containing 5.39 per cent. of manganese and 0.37 per cent. silicon) mixed with 300 grains of fine white sand, kept one hour at white heat in covered crucible contained in another, yielded a well melted product of 1460 grains. It was peculiar in appearance and nature, and was fibro-columnar. Was dull until burnished. On melting a piece of this metal, under charcoal, in a covered clay crucible, it was no longer columnar. After long digestion in hydrochloric acid, a light, bulky, black residue was left, consisting of carbonaceous and silicious matter. This residue was boiled with solution of caustic potash, and a colorless solution produced, thus showing that no carbonaceous matter had been dissolved, and there was an absolute black light residue which was washed and dried at 100° C.

If there had been much combined carbon, the solution in potash would have had a brown color.

Hence, we may say that spiegeleisen, at a high temperature, is acted upon by silica, so that the manganese is for the most part converted into the protoxide, which combines with silica to form slag, and most of the carbon is separated in the form of graphite which is replaced by silicon.

Abstraction of Silicon from Cast Iron by fusion with Sesquioxide of Iron alone, and with the addition of Manganese.—It seems that it has the power of abstracting the silicon, silicate of protoxide of manganese being formed.

Carbonate of the Protoxide of Iron, FeO, CO^2 .—Occurs abundantly in nature, in geological formations of

nearly every age. It is an important ore because of its general purity; crystallizes like calcspar, and is rhombohedral, and then it forms the mineral, sparry ore, or spathic ore which always contains more or less carbonate of protoxide of manganese and sometimes carbonate of lime and carbonate of magnesia; color yellowish-white, except when exposed to weather, and then it is brown, due to formation of hydrated sesquioxide of iron and an equivalent portion of CO^2 is evolved. The native salt, crystallized or not, is anhydrous, it is slightly soluble in water—more so by aid of CO^2 . When heated to redness, CO and CO^2 are given off, and magnetic oxide remains. Hydrate of potash abstracts CO^2 and CO escapes.

Action of Sulphuric Acid, or Hydrochloric Acid on Cast-Irons.—White Cast Iron.—Fetid hydrogen is evolved (probably due to the presence of a hydrocarbon), and a light, insoluble residue remains. On passing the hydrogen so formed through sulphuric acid, an oil remains which has excited considerable attention. It smells something similarly to petroleum.

Gray Cast Iron.—The insoluble residue for the most part consists of graphite; sometimes scaly, or crystallized silicon is present, according to some experiments. A cube of gray cast iron immersed in dilute hydrochloric acid till the acid was saturated, seemed spongy. White iron, thus treated, required three times as long to saturate the acid. It was spongy and like plumbago, and a piece put dry upon blotting-paper, became hot and caused the paper to smoke after a minute. Cubes of gray cast iron, subjected for two years to the action of dilute hydrochloric, or acetic acid, weighed but 22 per cent. of the original metal, and when exposed to the air quickly became hot, owing, Calvert said, to the rapidity of the oxidation of the iron.

Action of Sea-water on Iron.—Pig iron exposed to the action of sea-water for a long time, say years, seems to undergo the same change which occurs when similar irons are exposed to dilute hydrochloric acid. A spongy mass is obtained and the metal grows hot on exposure to air. This has occurred when cannon and cannon balls

long submerged, have been removed from the sea-water and scraped. Guns from the vessels of the Spanish Armada (1588), according to Wilkinson, were raised in 1740, off Mull, in Scotland, and they became so hot that they could not be handled. The cast-iron balls from a cannon made from malleable iron bars driven together by rings, became nearly red hot, while the bars remained of the same temperature, the cannon having been sunk in a naval engagement with the French off Portsmouth, in 1545, and raised 1836.

Alloys of Iron.

With Copper.—Mushet says that pure malleable iron may be united (by melting) with copper in any proportion, until it equals, or exceeds, the weight of copper. With 50 per cent. iron, the alloy possesses great strength—its hardness increases with the iron. But there is doubt as to the perfect homogeneousness of the union, and, therefore, Karsten says that iron can only take up, in actual metallic solution, a small proportion of copper, as copper can combine with only a small percentage of iron. He says that copper will act very little upon the magnetic quality of iron with which it is alloyed, and small proportions of iron may be detected by the magnet. This may be suggested to the magnetic electrician.

Karsten thought, after experiment on the large scale, that one-half per cent. copper to the charge, when converting cast iron into malleable on the charcoal hearth, did not render the cast iron hot-short. With one per cent. to the charge, iron of the lump would not weld properly, though the tenacity remained good. He states that thus alloyed it takes six times as long to dissolve in sulphuric acid, or nitro-hydrochloric acid, as pure bar iron does.

According to Prof. Eggertz, of Fahlun, malleable iron containing only 0.05 per cent. of copper, shows only traces of red-shortness. A patent has been taken in England for adding from $\frac{1}{2}$ lb. to 2 lbs. of copper to the ton, in the puddling process for rendering iron of a

"greater degree of hardness whilst retaining its ductility." Patented 1861.

1st. *Experiment.* Add 200 grains iron
 1000 " copper

Product, a well melted button, eight grains less than the metals used; copper-colored slightly; very tenacious and tough; lacked homogeneity; could not be drawn.

2d. *Experiment.* Add 300 grains iron
 1000 " copper

Fracture paler than copper; crystalline; granular; homogeneous.

3d *Experiment.* Add 700 grains iron
 700 " copper
 Loss 80 grains.

Button pinkish copper-red; brittle; fine grained; 50 per cent. iron. Mushet concluded that copper combined with iron in proportion as the latter was free from carbon.

Stengel arrived at the following:—

1st. All sorts of steel and iron, free from copper, when scaled by heating to redness and quenching in water, give a silver-white surface on the edges, whereas with 0.27 per cent. to 0.4 per cent. of copper, the surface thus scaled is black and rough.

2d. The presence of 0.116 per cent. sulphur and 0.192 per cent. silicon, without copper, renders iron and steel red-short and useless.

3d. The presence of 0.015 per cent. sulphur and 0.44 copper causes incipient red-shortness.

4th. A considerably less proportion of sulphur than of copper in iron, is sufficient to insure red-shortness as 0.1 per cent. of sulphur will cause more injury to the strength of iron than .75 or $\frac{3}{4}$ of one per cent. of copper and even a higher per cent.

According to Eggertz, steel made from iron containing only 0.5 of copper is useless. These facts are suggestive to the iron-master in the choice of his ores, especially in the region of ores similar to those copper and sulphur ores of Cornwall, Penn. This cupriferous iron, cast in moulds, comes out somewhat covered with a

sheet of copper, which causes the castings to assume a fine bronze color after exposure to the air.

With Zinc.—Molten zinc speedily takes up a little iron, yet no true alloy forms except by long contact. This occurs in the process of zincing iron in which a large quantity is kept melted in iron vessels, or when zinc vapor is passed through wrought iron tubes. Zincing, or, as it is termed, galvanizing, is practised to prevent rusting. The articles are thoroughly freed from scale by “pickling” *i. e.*, by washing with dilute hydrochloric acid, and then immersed in a bath of molten zinc covered with sal ammoniac, whereby they acquire a firmly adhering coating of this metal. A small amount of tin in the bath will give to the articles, thus galvanized, a singularly broken and lustrous appearance seen upon water coolers and other articles prepared in this manner.

The alloy of iron, in this process, causes a loss of zinc, which, the use of lead molten in the bath, will not wholly prevent for practical purposes, as the lead alloys with the zinc and does not at any rate cover all the iron in the bath. Large fire-clay lined baths are the only serviceable tanks for this purpose.

With Copper and Zinc.—Several alloys have been formed and patented, such as the German *aich* metal, and the Vienna sterro metal, from the Greek word, the meaning of which is “firm.”

With Tin.—This alloy we have illustrated in all tin ware, which is sheet iron the surface, only, of which is alloyed with tin. Karsten has shown that iron containing 0.19 per cent. tin is utterly worthless, being largely cold-short, and under a strong heat falls to pieces under the hammer, with a fine steely fracture and cannot be welded. From experiments in England, it was found that fused iron alloyed with $\frac{1}{11}$ of tin flowed like water, was white, received a beautiful polish, made a metal fine in tone when cast into bell form, and was dense as the finest cast steel; it was very brittle and hard, and resisted rusting. Tin with 2 per cent. of iron becomes magnetic. While iron and lead will not unite by fusion, tin and lead may be made to unite with iron, and this coating

produces the so called terne plate, an inferior looking "sheet tin" of commerce.

An English process (Mallet's) of zincing iron for protecting ships from rust or fouling, will illustrate the readiness with which zinc combines with iron. The ribs, or plates, for iron ships are immersed in a cleansing bath of equal parts of sulphuric, or muriatic, acid and water, used warm; the works are then hammered and scrubbed with emory, or sand, to detach the scales and to thoroughly clean them; they are then immersed in a preparing bath of equal parts of saturated solutions of muriate of zinc and sal-ammoniac, from which the works are transferred to a fluid metallic bath, consisting of 202 parts of mercury and 1292 parts of zinc, both by weight, (being in the proportion of one atom of mercury to forty atoms of zinc) to every ton weight of which alloy, is added about one pound of either potassium, or sodium (the metallic bases of potash and soda), the latter being preferred. As soon as the cleaned iron works have attained the melting heat of the triple alloy, they are removed, having become thoroughly coated with zinc.

The affinity of this alloy for iron is, however, so intense, and the peculiar circumstances of surface, as induced upon the iron presented to it by the preparing bath, are such that care is requisite, lest by too long an immersion, the plates become partially, or wholly dissolved. Indeed, where the articles to be covered are small, or their parts minute, such as wire, nails, or small chains, it is necessary, before immersing them, to permit the triple alloy to dissolve or combine with some wrought iron, in order that its affinity for iron may be partially satisfied, and thus diminished. At the proper fusing temperature of this alloy, which is about 680° Fahr., it will dissolve a plate of wrought iron, an eighth of an inch thick, in a few seconds. (Byrne.)

With Titanium.—It is only comparatively lately that we have become acquainted with this metal. Prepared by reducing the fluo-titanate of potash by potassium, it is an amorphous, grayish-black powder, resembling iron reduced by hydrogen at low temperature. Burns with

lively scintillations in the air, and like a flash of lightning in oxygen gas, titanous acid being the result.

It is frequently present in magnetic iron ores smelted in England and America. Found in the hearths of blast furnaces, in small crimson colored cubes, as cyano-nitride of titanium, though formerly considered titanium, and so spoken of in some books $\text{TiCy} + 3\text{Ti}^3\text{N}$. (Wöhler.)

Powdered rutile, titanous acid, TiO_2 , is used in attempting alloys of iron. Mushet has high faith in the improvement of steel by using titaniferous sand, called Iserine, and also titaniferous ores and irons. Others have failed in obtaining any special advantages from the alloy.

Method of determining Titanous Acid in Iron.—The alloy dissolves slowly in boiling hydrochloric acid, with exception of a little black residue, which disappears completely by ignition in contact with air. Precipitate the solution of the iron in nitro-hydrochloric acid, by ammonia; redissolve the precipitate in cold sulphuric acid, subsequently boil the solution thus obtained during a long time, when not the slightest precipitate appears if titanium is not found in sensible quantity. (Appendix A.)

With Lead.—Not satisfactory; there seems to be no alloy, but it is not fully settled.

With Antimony.—Causes, according to Karsten, cold and hot shortness, and is more injurious than tin.

With Nickel.—Liebig has examined some alloys of nickel with iron and steel; they had the appearance and properties of genuine Damascus steel, and acquired a magnificent damask.

With Silver.—According to Karsten, it produces effects similar to those produced by sulphur, even with .034 per cent. silver, the iron is unsound, laminar, and very red short. It is difficult of combination, or alloy.

Patents in 1861 and in 1863 were taken out in England for alloying iron with silver at the rate of from one to ten oz. to the ton, supposing it to be an improvement, but it is doubtful, as the treatment, in this particular case, in the puddling process might have been due to

the time and care in puddling; the care rather than the silver may have deceived the patentee.

Silver with steel, in proportion of one to 160, makes a steel with silver in fibres easily detected by solution in dilute sulphuric acid. Eight pounds of "very good Indian steel" to $\frac{1}{500}$ th of its weight pure silver, produces a steel harder than best cast steel, or than Indian wootz, and imparts a very favorable appearance.

With Gold.—Gold forms an easy alloy, and is rendered hard but not brittle when 22 parts of gold are alloyed with two of either iron, steel, or cast iron.

With Platinum.—Platinum alloys readily with iron, as sometimes is found out by the analytic chemist who uses his platinum crucible carelessly in this respect. A hole may readily be made through a strip of red hot platinum, by dropping melted iron upon it, although the melting point of platinum is greatly higher than that of iron. (Appendix F.)

Some iron-masters have shown their lack of knowledge of this fact by recommending platinum hearths, even in blast furnaces, and one gentleman of our acquaintance, deeply interested in the Bessemer process, was about preparing, at exceedingly great expense, for the lining of a steel converter with platinum, before he was persuaded of the fact above stated.

Experiment.—The proportion of 50 parts of steel to 50 of platinum makes the finest imaginable color for a mirror. Other proportions give various results.

With Rhodium.—The metals unite in all proportions. It produces a steel characterized with hardness and tenacity. Steel fused with its own weight of rhodium "gave a button, when polished, exhibiting exquisite beauty." Faraday and Stodart say this alloy of steel and rhodium is "the most valuable of all."

With Palladium.—4 pounds of steel to $\frac{1}{1000}$ of palladium, said, by Faraday and Stodart, to impart remarkable smoothness of edge to cutting instruments.

With Aluminum.—Deville says that aluminum and iron combine in all proportions. Iron tools used in stirring molten aluminum become coated.

Faraday and Stodart think that they have alloyed steel with pure aluminum by using alumina, thus: Pure steel, in small pieces, and, in some instances, good iron, was heated with charcoal powder, intensely, for a long time. When broken, the facets of small buttons (500 grains) were $\frac{1}{8}$ in. in size. This, broken and rubbed to powder in a mortar, was mixed with pure alumina, and all intensely heated in a close crucible for some time; an alloy was obtained, of white color, close, granular texture, very brittle; 700 of good steel to 40 of the alumina alloy fused together, gave a button, malleable, and, when forged into a bar, and the surface polished and acted upon by sulphuric acid, it gave that beautiful damask belonging peculiarly to the Eastern steel called "Wootz." It had all the appreciable qualities of best Bombay Wootz, though the latter is said, by some, to have no alumina appreciable by careful analyses. Karsten's plan of determining aluminum in steel, iron and cast iron, was as follows:—

Dissolve in nitro-hydrochloric acid, evaporate to dryness, moisten the residue with hydrochloric acid, and afterward dissolve in water, filter, precipitate with ammonia, redissolve the precipitate in the smallest possible amount of hydrochloric acid, then boil with excess of potash, dilute with much water, filter, acidify the filtrate with hydrochloric acid, and finally add excess of carbonate ammonia. Experiments lately tried at the "American Steel Works," Brooklyn, N. Y., show that iron, made as free from carbon as possible, and melted in clay crucibles with cryolite, forms a steel of great hardness and beauty of grain, but the effect of the cryolite upon the crucibles, due to liberated fluorine of which cryolite contains about 54 per cent. to 13 aluminum, caused the further use of cryolite to be abandoned.

With Chromium.—Iron and chromium may be alloyed in every proportion; the alloys are hard, brittle, crystalline, less fusible than iron; 17 per cent. chromium makes iron almost as white as silver, fibrous, brittle; 60 per cent. of chromium makes it whiter than platinum and so fragile as to be reduced to powder in an agate mor-

tar, and so hard as to scratch glass as deeply as a diamond. Very hardly attacked by acid, even with nitrohydrochloric acid.

These alloys may be easily obtained by heating, strongly, in brasqued crucibles, the mixed oxides of chromium and iron, and, when chromium predominates, should be intermixed with more charcoal, to prevent reduction. They may also be obtained from the chrome iron ores; but then a flux must be used to retain the silica and alumina which may be present in these ores, and a good flux is a mixture of

100 parts of glass (free from lead),
40 glass of borax,
100 ore. (Berthier.)

Fremy says an alloy may be formed by heating in a blast furnace oxide of chromium and metallic iron; it frequently crystallizes in long crystals, like needles, is like cast iron in appearance, and scratches the hardest bodies, even steel. Like chromium, it resists even concentrated acids.

The following *experiments* are from Percy:—

Use red hematite and sesquioxide of chromium, the latter formed by heating together chloride ammonium and bichromate of potash, washing out with hot water and igniting. Intimately mix your quantities and heat in charcoal lined French crucible, filling up the cavity with charcoal powder. Lute over and expose to white heat two hours.

Proportions taken by Smith in Percy's Laboratory:—

	1	2	3	4
Hematite	190	150	150	50
Sesquioxide Chromium . .	10	50	150	150
Carbon (charcoal powder*) .	*50	*50	†75	†50
(anthracite†).				
Metal weight obtained . .	152	145	229	147
Percentage	1	2	3	4
Iron (carbon present*)	*95.76	72.93	45.37	23.42
Chromium	4.24	*27.07	*54.63	*76.58

Each of these will scratch glass.

Experiment 1.—Well melted button splits under the hammer.

Experiment 2.—Well melted button, tin-white fracture, can be powdered.

Experiment 3.—Somewhat spongy button, easily crushed.

Experiment 4.—Less coherent than 3, centre portion filled with needle like crystals, fine reflecting surfaces.

1 per cent. to 2 per cent. chromium added to steel in the molten metal communicates hardness, and property of taking a beautiful damask, without reducing malleability.

Experiment.—1600 grains steel, and 16 grains pure chromium fused and kept so some time; button good, forgeable, no tendency to crack. Steel with 1.2 per cent. chromium gives a beautiful damask surface when etched with SO^3 .

In the process of converting cast iron into malleable, on the charcoal hearth, chromium is separated according to Karsten.

The alloy of chromium and malleable iron is now successfully made for the purposes of producing a steel of a remarkable property. Experiments with this steel in our presence prove that it will weld upon itself without any flux. It is not burned, or injured by overheating, but may, after a heat which will destroy cast steel (made by cementation), simply be brought to a cherry red and be tempered to a hardness sufficiently great to allow of cutting into any cast iron of low grades, as No. 2 or 3. What is remarkable is, that after overheating (to a white heat) and cooling without tempering, if it be broken the grain is large and coarse, but if the same piece of metal be heated to a low cherry red and then be plunged into water, the grain is found to be exceedingly fine, uniform, and similar to that of the best cast steel.

The method adopted is to melt the best malleable iron in large clay crucibles, avoiding all carbon. After the iron is melted, the broken chromate of iron ore is thrown into the crucible, so as to make about $3\frac{1}{2}$ to 4 per cent. of the whole mass. The ore used is the chromate from

near Baltimore, Md. The present price of the ore (\$55 per ton delivered in Baltimore) is the only drawback to the cheapness of the steel. Preparations are being made to enlarge the operations and roll the steel into bars. The works are in Kent Avenue, Brooklyn, N. Y.

With Tungsten.—By reducing tungstate of ammonia (crystallized) in a current of hydrogen, at a red heat, the metal is obtained in the form of crystals, with bright metallic lustre and tin-white color.

Tungsten, or Wolfram steel, was announced as an important invention, and said to be especially valuable for cutting and boring instruments, fine in grain, uniform, hard, tough, and of superlative quality. But there are said to be some doubts as to the perfection of the steel, and that some razors, files, &c., sold as Tungsten steel, are not such.

On the whole, the tenacity and tensile strength of the alloy, under certain proportions, is remarkable.

With Potassium.—Iron filings in a tube exposed at a high temperature to the vapor of potassium, forms an alloy; it is flexible and, sometimes, soft, so as to be cut with scissors, and even scratched by nail; decomposes water.

A mixture of iron filings exposed to a very high temperature with bitartrate of potash, forms an alloy.

	336 grains iron,
	1504 bitartrate of potash,
Yielded a large button of	74.60 per cent. iron,
	25.40 " " K, <i>i. e.</i> Fe ⁴ K.

The alloy resembled malleable iron, could be forged and welded, yet at ordinary temperature it could scarcely be indented by a heavy sledge hammer, or cut by a file. It oxydized under water and in moist atmosphere. With carbonate of potash "no results were obtained."

With Calcium.—It has been stated that when linings of limestone had been used, the iron was apt to be red-short. Calcium is said to be found in some cast irons, but little is known of this alloy.

With Magnesium.—Nothing very definite is known ; it is said in some analyses to have been traced.

With Vanadium.—The presence of an appreciable quantity, 0.38 per cent. of vanadium in the iron made at the Acklam furnaces, at Middlesborough, belonging to Messrs. Stevenson, Jacques & Co., is likely to become the subject of much interest among chemists. The iron possesses a high degree of strength, and though found, in minute quantities, in iron made from the magnetic ore of Taberg, Sweden, it is supposed to render it a first-rate iron for wire drawing. It has been found in pig iron from the Oolitic brown hematite of Wiltshire, England, and in Cleveland ores and those of Southwest Germany.

We learn that Mr. Mushet is of the opinion that Vanadium, in a minute mixture with iron, is a most valuable alloy, giving a fine, tough, fibrous texture to bar iron.*

CHAPTER IV.

THEORY OF FLUXES.

General Principles and Introductory Practice.

THE principle upon which the use of all earthy fluxes is based, is, that, practically, no earth is fusible alone ; argillaceous and silicious earths together are infusible, so with argillaceous and magnesian—so with silicious magnesian, but, when calcareous earth, lime, or limestone, is added to any mixture of the other two all will combine and run into glass which will become thin, with the same heat, according to the skill in proportion and treatment.

M. D'Arcet, a French chemist, made this experiment : he put into three crucibles, respectively, a ball of clay, a quartzose, or silicious sandstone ball, and a limestone or chalk ball, and exposed them to heat so great

* Engineering, April 3d and 12th, 1867.

that the chalk ball fused slightly, where it had touched the sides of the crucible. They were unmelted. He then mixed them, and, in the same fire, they ran into a thin and transparent glass.

Kirwan found that argillaceous and magnesian, argillaceous and silicious, and silicious and magnesian earths would not melt in any proportion, but that silicious and calcareous earths, argillaceous and calcareous, by very strong heat, would vitrify, but not perfectly. When the earths are calcareous, argillaceous and magnesian, it requires a double proportion of the calcareous to make a glass. No glass can be made if the clay earth, or magnesian predominate. It has been found that the calcareous earth, argillaceous and silicious earths, or calcareous, magnesian, and silicious can be brought into perfect fusion, if the calcareous somewhat predominate. With a strong heat, argillaceous, silicious and magnesian earths may form a glass without lime, and this is the only combination he tried that would thus produce glass without lime.*

The metallic oxides (iron, of course, included) aided the fusion. Note, that, common clay sometimes contains one-half, or more, of its weight of sand intimately mixed. If clay predominate in the iron ore the flux indicated is limestone, and if the iron be, on the contrary, mixed with limestone, the proper flux is not limestone, but clay.

Herein consists much of the practical knowledge in mixing ores so that they may flux one another, which are with difficulty fluxed alone.

Hence the necessity of a knowledge of the composition of ores to prevent the loss of fuel, of time, and of iron, by the iron becoming entangled in the scoria, or in a thick unyielding slag.

It is plain, therefore, that we should begin by a knowledge of the earthy parts contained in the ore; or, in other words, we see the necessity of an analysis of the ore about to be reduced.

* Mushet.

The object of such an analysis is (having previously found your ore to be worth working) to discover what proportion of the materials, already mentioned, your ore will require, so that, with the greatest economy, you may obtain the most perfect fusion of these earths contained in the ore, that the metallic iron, being released, may be reduced.

The following very general, and, merely approximate methods of determining the composition, may serve as introductory to exact methods. They are not accurate, but their inaccuracies will be shown. They exhibit former methods, for they were recommended to, and are now adopted by, some superintendents, without the correction. The first process is to test for limestone, and the following method has been recommended: Take 400 grains of the ore, in fine powder, selecting for that purpose, at least, one half dozen fair average specimens, put this into a glass flask, and pour upon it $\frac{1}{2}$ oz. muriatic acid previously diluted by twice its volume of water. Nearly boil it for one half hour. If there be no effervescence there is probably no limestone, and you may proceed no further. If there be, continue to add hydrochloric acid and water till effervescence ceases. Let stand 3 or 4 hours, then add $\frac{1}{2}$ pint of water, stir well, and filter through any strong, clean, unsized paper, placed in a glass funnel. Wash what remains upon the filter paper with one-half pint more water slowly poured upon the side of the funnel. This process, thus far, will dissolve all the calcareous earth, and also some ore and other matter, but this latter is of little moment. Now add to the filtered liquor 2 drachms, by measure, of sulphuric acid, which will throw down sulphate of lime, or gypsum (CaO SO^3). Let it rest, and add a little more SO^3 till no more precipitation takes place. Pour off the supernatant liquor, add $\frac{1}{2}$ pint hot water, and filter, washing your precipitant till the water passing through is not sensibly acid to litmus paper. Let it drain 24 hours. Remove all sediment, or better, let it dry on an ordinary stove, at 120° Fah., till powdery, when 100 grains will represent 227 grains of limestone. Another,

and more accurate method, is to expose a weighed lump of the ore, one-half hour, to a bright red heat in a crucible. Now, in 100 parts of limestone, or of pure carbonate of lime, CO^2 combines with CaO in the proportion of 44 to 56, and hence in the last method, 100 grains of loss of weight will represent the amount of CO^2 driven off, which is equivalent to and must have belonged to the 227 grains of carbonate of lime, or limestone, existing in the ore before heating. The reasons for the proportion first stated are as follows: Every 68 grains of sulphate of lime contain as much caustic lime (that is lime uncombined with CO^2) as would form fifty grains of pure limestone, or carbonate of lime. The proportion then is as $68:50::150:110$, or $68:50::$ the weight of sulphate of lime obtained is to weight of limestone in the ore. But in these practices we make the following *corrections*. In the first case, the SO^3 does not precipitate all the lime to the amount which the above proportions would represent, the proof is discoverable thus, evaporate the filtered liquor, running off from the sulphate of lime caught as above directed, to one quarter the amount. If the method is followed out as directed, there will be, before evaporation, about one quart and a half, or 42 fluidounces. This amount evaporated to one quarter will leave about one-half pint. Now add good strong alcohol in bulk, or volume, nearly equal to the amount of liquor remaining after evaporation, and, immediately, there will appear a rather large precipitate of sulphate of lime, because, while the latter was soluble in water, it was not in alcohol. Hence the process needs this correction and then the proportion would be exactly $150:110$. But, if thus performed, there is no need of taking more than 100 grains, and if the scales will weigh accurately so small a quantity as the tenth of a grain, or less, then 20 grains, or less, are quite sufficient. Hence the convenience of delicate scales, and the saving in material and such tests as alcohol, &c.

Again; in the second method we have another practical difficulty, for most ores contain more or less water, as shown on pages 28, 29, 43. This method, there-

fore, requires that account be taken of the weight lost by driving off the water chemically combined, as well as that which was merely moisture. Hence in that proportion, 100 : 227, about from 10 to 20 per cent. must be deducted from the weight lost, for water driven off. Practically this makes a difference of importance when buying ores by the thousand tons or more, and iron-masters who speak of making so much iron from so much ore, without stating the kind of ore, should recognize, in their calculations, the amount of water in the ore, which is chemically combined in some ores to the amount of 400 lbs. to the ton of ore, while, in others, it is not more than 50 lbs. to the same amount.

For determining the carbonate of lime, another way is recommended, namely, the displacement of water by the carbonic acid formed by adding HCl (acid) to the powdered ore. Thus, a one pint bottle holds as much air as would represent the CO_2 gas of 31.13 grains of pure carbonate of lime thus treated with hydrochloric acid, and any part of that pint would represent a proportionate part of 31.13 grains of pure limestone. Hence a bottle or flask may be filled with hot water, inverted in a vessel of water, taking care to leave no air in the bottle. A bent tube conveying the CO_2 gas from the mouth of the bottle, containing your ore powder to be analyzed, to this inverted and filled bottle, will complete the apparatus. Having measured the water in the bottle and the vessel of water through which the tube was conveyed, all that remains after the gas ceases to come over, is to keep the mouth of the inverted bottle under water till corked, remove it, set it upright, remove the cork and measure the amount of water necessary to replace that which was displaced by the gas, then you have the proportion, as one pint is to the amount displaced, so is the 31.13 grs. to the amount of limestone in the ore. When scales of the proper size are to be had, the bottle may be weighed previously to the introduction of the water; the water introduced, weighed, and after the displacement by the water, it may be carefully wiped, the cork removed, and then weighed to find the loss, which pro-

portioned will give the exact amount of gas. If one pint weighs one pound (29 cub. in.=1 pint) then one pound : the weight lost :: 31.13 : the limestone in the ore.

This method might, by some ingenuity, be made very accurate and convenient, were it not for the fact that the water, if used, must be hot, else it will absorb some of the gas and render the loss less than it appears to be. These methods will serve as an introduction to the methods of analyses and the precautions necessary. The only correct method of determining amount of limestone, when no other carbonates exist, is by weighing the powdered ore, or mineral, in a small flask, or bottle, and also a sufficient amount of HCl acid diluted, then pouring the latter into the bottle, and when all effervescence has ceased, by means of a tube blow out carefully all CO² remaining, and the loss of weight of the materials combined will give the CO² in weight and the following proportion, 22 : 50 :: amount lost : limestone in the ore.

Argillaceous ores may be detected, in some degree, by their earthy smell and by adherence to the tongue, which facts are not known to exist, to any considerable degree in silicious and calcareous ores. If the ore is argillaceous (aluminous), more lime must be added as a flux. The method of determining the ingredients of alumina we will defer stating for the present. If your ore be a calcareous ore, it would be absurd to use a limestone flux; your flux might be half its weight of clay.

If it be a silicious ore, it will require both limestone and clay.

The *quality* of your iron, as well as *quantity*, depends upon these distinctions, as we shall see hereafter more fully.

Mr. David Mushet, of the Clyde Iron Works, England, was enabled to produce, in his assay furnace, iron of all the varieties of strength and fusibility which are made on the large scale, and that by the simple application of lime, or chalk, in various proportions as a calcareous earth, and common bottle glass, in the place of silex, to constitute fusibility. In no case was the assay con-

sidered perfect unless the vitreous mass, or slag, presented the transparent appearance of flint glass, or a slightly darkened shade of azure. This last is the surest proof of the non-existence of iron in the state of fused oxide in the slag. Besides, this pellucidity enables you to detect the smallest globule of metal which may have been suspended during fusion. In all these cases of good slag the quality of iron is that of a gray, or it may be called richly carbonated, and the button possessing a "smooth, silvery, greasy feel upon the surface." On the other hand, opacity of scoria, or slag, always showed a degree of iron oxide remaining, disseminated, or combined, throughout the slag. Green indicates the initial quantity of unreduced protoxide, and that color changes to brownish-brown and black when as high as 12 per cent. may be found amid the slag.

Another difficulty may be encountered in the dispersing of the iron of the ore in a large number of various sized globules of the richest crude iron in and on a semi-vitrified opaque mass of scoria of a grayish-blue, mottled, or whitish color, being due to deficient flux.

This difficulty shall be studied and met with hereafter.

If ores are smelted without the addition of any other substance, the product, if iron, will be proportioned to the quantity of lime contained in the respective ores. The following assays will illustrate.—

1. In a crucible with well fitting cover, 875 grains pulverized silicious ore, in its natural or "raw" state, were introduced, and heat, as usual, applied from a blast. In 12 minutes the ore was in perfect fusion, much agitated, and emitting large bubbles of ignited gas of fiery color. In 40 minutes the crucible was withdrawn. In this state a small rod of iron introduced through the scoria showed a button which ignited on contact with the air, and continued to ignite brilliantly till the scoria closed over it. When cold a well formed button was found of extremely oxygenated, or decarburized crude iron; weight 219 grains, produce equal to 25.1 per cent. from the raw iron ore. The scoria showing black color, firm and

weighty, of 402 grains, so that the loss was 254 grains, equal to 29 per cent. The metallic button was white as silver, presenting imperfect radii.

2. Same amount treated, of an argillaceous ore containing a moderate proportion of lime, fusion more difficult, though the phenomena alike to those in experiment 1. The crucible was withdrawn in 40 minutes as before. Deflagration similar, weight 249 grains, produce equal to 28.5, vitreous mass weighed 354 grains, loss 272, or 31 per cent. Fracture still white, no particular crystallization, glass deep brown, shining color and tinted.

3. Same experiment with calcareous ore, fusion required violent heat of 17 minutes, and a gaseous substance plainly disengaged, otherwise the same as before. Result a carby-oxygenated crude iron 261 grains, produce equal to 30 per cent. from the raw ore. Vitreous mass opaque, brown, streaked with white, 294 grains, loss 320 grains, 36.5 per cent., button smooth, crystallized surface, combined, when in fusion, less readily with oxygen in the atmospheric air than did the two preceding; fracture light gray with a distinct grain. Vitreous mass in radii shooting from a circumference of a minute circle to that of one larger.

Thus it is plain that buttons or "reguli" of crude iron may be obtained from the different classes of iron ore, of a considerable per cent. produce, without any addition whatever, and the tendencies which they have to part with their iron being in proportion to the amount of lime they contain. The epitome of the foregoing experiments is as follows:—

Silicious iron ore, properly assayed, yielded 34.5 per cent. by fusion, *per se*, only 25 per cent.—9.5 being mixed with scoria.

Argillaceous iron ore, properly assayed, gave 35.6 by fusion, *per se*, 28.5—7.1 in scoria.

Calcareous iron ore, properly assayed, 33.7 by fusion, *per se*, 30—in scoria 3.7.

The thing to be desired is such a mixture in the ore,

or with it, that no iron will remain behind, either as metallic iron, or as oxide of iron in the slag.

Table of proportions of fluxes.—Practical experiments. (Mushet.)

1st variety, Argillaceous Ore: let it be considered to contain:—silex 3, clay 9, lime 6=18.

					Grains.
To assay	4	troy	ozs. of this ore	or	1920
add	4	"	" bottle glass	"	1920
"	3	"	" chalk or lime	"	1440
"	$0\frac{1}{2}$	"	oz. charcoal	"	240
Total					5520

2d variety of same iron contains:—silex 7, clay 10, lime 3=20.

To assay	4	troy	ozs. of ore	or	1920
add	4	"	" glass	"	1920
"	4	"	" chalk	"	1920
"	$0\frac{3}{4}$	"	oz. charcoal	"	360
Total					6120

1st variety, Calcareous Ore: contains silex 4, clay 6, lime 14=24.

To assay	4	troy	ozs. of ore	or	1920
add	5	"	" glass	"	2400
"	$1\frac{1}{2}$	"	" chalk	"	720
"	$0\frac{3}{4}$	"	oz. charcoal	"	360
Total					5400

2d variety of same ore contains: silex 6, clay 4, lime 10=20.

To assay	4	troy	ozs. of ore	or	1920
add	4	"	" glass	"	1920
"	2	"	" chalk	"	960
"	$0\frac{1}{2}$	"	oz. charcoal	"	240
Total					5040

1st variety Silicious Ores: say contain silex 12, clay 8, lime 5=25.

To assay	4	troy	ozs. of ore	or	1920
add	4	"	" chalk	"	1920
"	3	"	" glass	"	1440
"	$0\frac{3}{4}$	"	oz. charcoal	"	360
Total					5640

2d variety Silicious Ore: say contains silex 10, clay 5, lime 7=22.

					Grains.
To assay	4	troy ozs. of ore	or		1920
add	$3\frac{1}{2}$	" " chalk	"		1680
"	3	" " glass	"		1440
"	$0\frac{3}{4}$	" " charcoal	"		360
<hr/>					<hr/>
Total	$11\frac{1}{4}$				5400
Equalized ores, say contain :—silex 7, clay 7, lime 7=21.					
To assay	4	troy ozs. of ore	or		1920
add	$3\frac{1}{2}$	" " glass	"		1680
"	$2\frac{1}{2}$	" " chalk	"		1200
"	$0\frac{1}{2}$	" " charcoal	"		240
<hr/>					<hr/>
	$10\frac{1}{2}$				5040

These proportions, Mushet thinks, make, as types, the average fluxes for general iron ores, of these three classes, the improvement upon which is to be suggested by the color and transparency of the slag and the degree of carburization of the button.

By a slight variation of the proportions, the metal, from the same ore may be made to pass through all grades of iron, from good to the most inferior.

In order to show how much the iron produced, from any ore, may be altered, or modified in properties, take an ounce of the oxide of pure malleable iron; introduce this oxide, alone, into a covered crucible and expose it to a violent heat for 40 minutes (or longer, if a larger quantity) and a button of highly decarburized iron will be obtained:—expose it longer and a small mass of malleable iron will result. The produce, in either case, will be short of the quantity of iron in the original mass. When "oxygenated" iron is obtained, the ore from which it was obtained is said to contain "*bad iron*." That this is not always due to the iron may be proved by taking another equal part of the same oxide and mixing it with a little chalk, and with some glass to constitute fusibility, and expose it to a degree of heat equal to that used in the former case—the iron will be reduced to fine gray or

carburized iron. Here is a different iron from the same ore. Again, use the same oxide and add triple the glass (or double, by weight), expose as before—the iron will be reduced, but, it is no longer gray iron, but brittle and white. This shows the importance of correct fluxes, both in regard to nature and quantity of the metal produced from the same ore.

Fluxes for the Blast Furnace—Practice with Fluxes—Laboratory Assays.

Any substance which promotes the melting of another is called a flux. The term is specially applied to those materials which promote the melting of earths and the separation of the metals from their oxides. Of this class it is our intention at present to speak.

Fluxes are most important matters to the metallurgist; they test the practical science of the iron master; indeed, they are the chief science of his whole business. We have spoken of the theory of fluxes, and shall now turn attention to the materials used as fluxes in the blast furnace.

Fluxes, in practical use in the blast furnace, are lime under various forms, clay, silex, and the foreign matter in the fuel. These are used separately, or ores, largely containing these fluxes, are used, as fluxes, for economy.

Lime.—Limestones are generally applied in the blast furnace instead of lime. The distinction has been made in the previous pages. The stone is preferable, for reasons we intend to explain in another chapter. Pure limestone consists of lime (Ca O), the oxide of calcium, and carbonic acid (CO^2 .) It is sometimes mixed with oxide of iron, alumina, silex, magnesia, phosphoric acid, in combination, and sometimes sulphuric acid, also in combination. The purer kinds are known under the following names:—

Calcareous Spar.—Occurs in crystals, or in white crystalline masses dissolves with effervescence in muriatic and some other acids, without residue, if pure; loses by calcining, if pure, nearly 44 per cent. of carbonic

acid gas (exactly 43.88), and becomes caustic, or quicklime.

Stalagmites, stalactites, chalk, and calcareous tufa are limestones, or concretions more or less impure. The variegated brownish-yellow ornamental stone, called California marble, belongs to the stalagmites, colored by a little iron and other elements.

Marble may, generally, where the crystalline structure is distinct, be considered a pure limestone, and forms an excellent flux for silicious ores.

Limestones of the coal formations may differ much in various beds; but in the same bed limes of different purity may occur often mixed with iron, magnesia, &c.; and fossiliferous limestones frequently contain phosphorus in some combination.

[*Oyster Shells* form a very good flux, and may be used where they can be procured in sufficient quantity, and at reasonable prices.

The composition of the limestone to be used in a smelting operation ought to be known to the manager, as well as that of the iron ore. The composition of iron ore can be very frequently guessed at; at least so far as the ores are calcareous, silicious, or aluminous; but with limestone this cannot be done, for limestone composed of fifty per cent. of lime and fifty per cent. of foreign matter can, sometimes, hardly be distinguished from a far purer carbonate. It is a matter of very great importance that the manager of furnaces should know the exact composition of his limestone, even though he knows the composition of the ores. If calcareous ores are to be smelted, it would be improper to add marble for fluxing; in these ores a silicious limestone, or silicious slate should be used. If clay, or aluminous ores are the main material from which iron is manufactured, a magnesian limestone is preferable; but an aluminous limestone should be used where silicious ores form the body of the material.

To know, at least qualitatively, the composition of the limestone in use is of the utmost necessity, as we shall hereafter show. And to enable the practical super-

intendent to analyze his limestone, we shall present a brief method of investigating the qualitative composition of limestone.

The first operation is to weigh a piece of limestone, or to take an ounce of limestone, burn it in an iron pot or crucible, and weigh again.] Repeat the work until it ceases to decrease in weight. The difficulty found in the same experiment with the ore does not exist in this case, for the moisture, or combined water, amounts practically to nothing. [If the limestone loses, in calcining, forty-three or forty-four per cent., that is, if there is little more than half an ounce left as burnt or quicklime, we may consider the specimen pure limestone, for carbonate of lime is composed of fifty-six per cent. lime and forty-four carbonic acid. If the specimen loses, in burning, only twenty or thirty per cent., we may expect a large quantity of foreign matter, which is to be found by chemical analysis in the wet way.

Where we suspect foreign matter in the limestone, the burnt specimen should be moistened with rain water, and stirred until properly slacked or dissolved. If the limestone is bad, or if it is burnt too hard, it may happen that the lime will not slack; but if the carbonic acid is all expelled (which we find by adding sulphuric or any other acid to the lime solution), this is of but little consequence. If the added acid produces effervescence, the lime is imperfectly burnt, and we are then obliged to burn another specimen, and proceed in the same way until an acid will act upon it without producing carbonic acid gas. If the lime is well burnt, no effervescence occurs, and we may add to the watery hydrate of lime sulphuric acid, drop by drop, until it is saturated; that is, until litmus paper is reddened in the solution. No harm is done by warming the whole, and even boiling it until no more acid is absorbed, and the solution retains its acid character. This solution is filtered, and the clear liquid precipitated by solution of caustic potash, or, what is better, by caustic soda; which, if the solution is dilute, throws down all the magnesia and any iron that may be therein, and keeps the alumina in so-

lution if there is any dissolved; but this seldom happens if the first solution was not boiled too long. Alumina, dissolved along with the magnesia, may be precipitated by ammonia, or carbonate of potash. In this way, if there is any magnesia, we find it; and silex and alumina are generally left in the filter paper.

To separate alumina and silex from the limestone, we pound the limestone into fine powder, pour over this powder strong sulphuric acid, and boil. The alumina, magnesia, iron, and manganese are dissolved by adding, gradually, enough water to keep the mass liquid. After we think all is dissolved that can be dissolved, we pour on more water, and add a surplus of acid; this prevents the lime from being dissolved. Filter. The solution is then treated with ammonia to slight excess, when iron is precipitated along with the alumina; or with solution of caustic potash, when the iron, but not the alumina, falls; the latter may be precipitated from the filtrate by ammonia. We may thus approximately find the amount of alumina. Silex mixed with the lime will generally remain in the filter from the first filtration.

If, after the above experiments, we suspect that the main body of foreign matter is silex, it is best to pour over the pounded limestone nitric acid, which dissolves everything but silex; and we may filter and wash the residue, which will be the exact amount of silex in the limestone. These are the simple means by which the composition of limestones, so far as is required for practical purposes, may be approximately ascertained. A large amount of iron in the limestone is not actually hurtful, but, if we want to make gray iron, may be injurious; for such limestone is generally inclined to produce white iron, and often black cinders, in a hot furnace.]

As this subject is one of great importance we add a still more accurate and condensed method for those wishing to make more accurate analyses of the stone for other material as well as for lime and magnesia.

Analysis of Limestone.

Principal Constituents, Composition, and	Equivalents.
Carbonic acid gas, (CO ²)	22.0
Lime, (CaO)	28.0
CaO CO ² (=22+28)	50.0
Magnesia, (MgO)	20.0
MgO CO ² =22+20	42.0
Silica, (SiO ³) (in new equivalent 30) . .	38.0
Alumina, (Al ² O ³)	51.5
Protoxide of iron, (FeO). . . .	36.0
Peroxide of iron, (Fe ² O ³)	80.0
Water, (HO)	9.0
Phosphoric acid, PO ⁵	71.0

The following is the method of determining the proportion of these important constituents.

1. Weigh a specimen carefully; calcine in a Hessian, or clay crucible, and weigh again as directed before; this weight gives CO²+HO; but if well dried at 212 Fahr. (red heat drives off CO²) HO need not be taken into calculation.

2. Weigh another specimen, say of 30 to 80 grains, pulverized to impalpable powder, or pass through a sieve of 60 to 80 holes to the linear inch; mix with three times its weight of lump caustic potash, or caustic soda, and heat to redness in a silver crucible till thoroughly melted, dissolve the whole in slightly diluted hydrochloric acid; heating the acid makes it dissolve more rapidly, that is, heating the hydrochloric acid to 200° Fahr., its boiling point, or to about that heat. Evaporate the solution till it becomes thick and pasty or even dry, stirring it continually toward the end of the process. This shows that the silica has coagulated, mix the paste with eight or ten times its volume of boiling water; this dissolves all except the *silica*; filter; wash well the precipitate, preserving *all* the water which comes through the filter; dry, calcine, weigh; the *silica* is now obtained.

3. To the filtrate add pure aqua ammoniæ (not the carbonate) in slight excess, and if not previously very acid, about $\frac{1}{30}$ part solution of chloride of ammonium before

adding the ammonia. This precipitates alumina, oxide of iron, but, because of the chloride, no magnesia; filter, wash, dry. Then evaporate the filtrate until much reduced in bulk. Add milk of lime by degrees so long as any precipitate falls. This precipitate is the remainder of the *magnesia* if any fell before from neglect of use of chloride of ammonium. Wash this precipitate, dry it, heat, weigh; add this weight to that of 1 and 2 and subtract the sum from the whole weight of original specimen and the remainder equals the weight of lime, for 1, 2, 3, are, just here, supposed to contain all but the lime.

4. Now, by reference to the equivalents previously given, from the total carbonic acid found by process 1 (proportioned to the weight of specimen used in No. 2), subtract the weight of *lime* (found by process 3), multiplied by 22, and divided by 2.58, and you obtain the CO^2 which existed in combination with the magnesia, and this remainder multiplied by 20.7 and divided by 22 will give the quantity of *magnesia* in combination with CO^2 .

5. Subtract the result of 4 from that of 3, the result will be the quantity of alumina and oxide of iron and of magnesia combined with silica if any, but so far as limestones are known, the magnesia exists always as carbonate; none may be considered as brought down by alumina if the precautions were taken.

To *separate the alumina* from the iron, boil both in solution caustic KO; this dissolves the alumina and leaves the iron; wash with hot water carefully and patiently till neutral, and no signs of potash in filtrate, the iron remains pure Fe^2O^3 , dry, heat to low red heat, weigh. Evaporate filtrate till reduced to small volume, and precipitate alumina by ammonia. Wash, dry, heat, weigh.

The most important part is the amount of carbonate to silicates. This may be found (nearly) by this formula $\text{CO}^2 \times 2.3$ if the *limestone is not magnesian*, $\text{CO}^2 \times 2.12$ if there is one equivalent of MgOCO^2 for each equivalent of CaO, CO^2 .

This CO^2 is that found by process 1. The truth will most always lie between those limits. The remainder of the stone may be considered *silicates*.

Instead of the milk of lime, the more accurate method is to treat the filtrate after ammonia, as in 3, has been added and as described above, first, with pure solution of carbonate of potash, or of soda, and thus precipitate both the lime and magnesia; dry this precipitate and then wash with boiling water, add then cautiously (a few drops at a time) pure SO^3 until slightly in excess, evaporate all to dryness, and the dry residuum ignite in a platinum crucible to expel any free SO^3 , or excess of SO^3 . This dry mass is now weighed, for it contains the *lime* as sulphate of lime, insoluble in a saturated solution of lime, and the *magnesia*, or sulphate of magnesia, quite soluble in the same menstruum. The dried mass is therefore digested thoroughly in the saturated solution of sulphate of lime, filtered, the undissolved sulphate of lime in the filter is washed with the solution of sulphate of lime till all the soluble sulphate of magnesia has passed through; dry, ignite, and weigh. Subtract this weight from the weight found of the whole mass before the magnesia sulphate was dissolved out, and the remainder is to be accredited to the sulphate of magnesia. Then the weight of the sulphate of lime obtained, after heating, is to the pure oxide of calcium, or lime (CaO) as 60 is to 28, *i. e.*, every 60 grains, or grammes of ignited sulphate of lime contains 28 grains, or grammes, of pure lime. And every 68 grains of sulphate of magnesia (ignited) contains 20 grains magnesia (MgO). Thus we have the *lime* and the *magnesia* correctly. It becomes often a matter of very great importance to the metallurgist to learn the amount of *phosphoric acid* in a limestone. Proceed thus: Pulverize, weigh, ignite to red heat, weigh (difference is as above, CO^2), dissolve in muriatic acid, either by heating, or otherwise, until dissolved, residue may be silica in shape of sand, or it may be sulphate of baryta, unimportant at present; filter, if there is such a precipitate, and wash it; carefully neutralize with ammonia; if there

is any precipitate redissolve with addition of least possible amount of muriatic acid, adding a little solution of acetate of soda; add solution of oxalate of ammonia, the precipitate is oxalate of lime, delicately complete the precipitate, let it settle and boil, else it will pass through the filter paper. Filter, wash. Carefully saturate with ammonia; this precipitates the magnesia with its corresponding equivalent of PO^5 ; the whole weight is to PO^5 as 91 is to 20, *i. e.*, 91 grains have 20PO^5 . Some PO^5 remains in the filtrate may be precipitated by solution of sulphate of magnesia, mixed with chloride ammonium and ammonia, and let stand in a warm place an hour or more, the precipitate washed with water containing 1 part to 3 of ammonia, dried and ignited, weighed. 111 grains of this precipitate ($2\text{MgO}, \text{PO}^5$) contains 71 grains PO^5 .

[*Clay*, where it can be had of proper quality, is a most important material in the furnace. It is to be applied where silicious ores, which furnish weak metal, are chiefly smelted. Lime fluxes well in such cases, and yields gray metal very readily; but the metal, however soft it may be, is generally weak. An addition of clay, or aluminous shales, or, what is far better, clay ores, or ironstone, will improve the strength of the metal, as well as the working in the furnace. Pure clay, in whatever form, is bad; it clinkers before the tuyere, and troubles the furnace men. If a ferruginous clay (red clay) can be had, it is by all means to be preferred; and in case red clay contains but a small percentage of iron, or cannot be procured at all, blue clay, which generally contains more or less phosphate of iron, may be applied. In the latter case, however, we should be cautious as to the amount, for too much may injure the quality of the metal. Clay, under all conditions, is the best material to improve the strength of the metal, and deserves attention on that account.

Silex.—Calcareous and argillaceous ores generally work very badly in the furnace, whether used singly or together; and are apt to furnish white iron. The best

and only way to obviate such evils is to add either silicious slate, or shale. Sand, or pure silex is, like pure clay, not to be recommended. If ferruginous shale is to be used for fluxing, the shale or slate must be roasted or burnt like ore, until all volatile matter is expelled, and the iron, which is generally in the form of protoxide, is oxidized into peroxide. If ferruginous silex is added to the ore charges in this way, the result is generally favorable.

Another flux, which influences the progress of the smelting operations, besides the artificial fluxes, and the foreign matter in the ores, is the matter contained in the fuel, the ashes; these form accidental fluxes, but are of importance in the operation. The ashes of wood, and charcoal of wood, generally contain a preponderating amount of alkali. This alkali may be considered beneficial as an electro-positive agent of fluxing, and facilitates the reviving of metal, as well as the fluidity of the slag, where the mixture of ores and artificial fluxes is composed of a predominating amount of silex and clay. The ashes of mineral coal and anthracite contain principally silex and clay, and may be considered electro-negative. They will be fluxes where the ores contain a preponderance of lime, magnesia, or of the alkalies. How far such matters have any influence upon the success of smelting operations, will be shown in another place.]

Varieties of Limestone and Lime.—1. *Pure, Rich, or Fat Lime*, produced from stones containing little or no silicate, slacks, by absorbing water, in the atmosphere gradually hardens, but not at all under water. Such lime is made, by continued bright red heat, from stones consisting wholly of CaO CO_2 , which loses 44 per cent. of its weight by burning, and leaves 56 per cent. lime.

Weight of the coal consumed in burning is from $\frac{1}{5}$ to $\frac{1}{6}$ of that of lime burned.

2. *Hydraulic Limes*, from stones containing from 10 to 30 per cent. silicate; they slack but less rapidly than those of No. 1, and harden slowly under water. They contain silicates of alumina and sometimes carbonates of

magnesia, generally compact, gray, blue, brownish-yellow, according to organic matter, or oxides contained in them.

The following tests may be applied: Of the stone, calcine two or three cubic inches in a crucible, pulverize; make into stiff paste with water; form into a ball; immerse in a glass of water. If it is hydraulic lime, it will harden under water so as, at least, to resist the pressure of the finger, and in a time varying from 24 hours to a fortnight, and, if the quality is good, in a month will be like medium limestone in hardness. If it is cement, it will harden in a few minutes. The best kinds of hydraulic limes slack so imperfectly that they must be pulverized in a mill (generally formed of rolling stones in a circular trough). They should be kept perfectly dry until used, or be reheated before used. It is a mixture of quicklime with silicates of alumina and iron, and sometimes with magnesia.

The hardening under water is due to the formation of artificial stone from the chemical combination of double compounds, and, perhaps, by the chemical absorption of the water into a solid state similar to that of crystallization.

The difference between hydraulic lime and cement, appears to consist in the varying amount of lime; in the former it exceeds that amount sufficiently to neutralize the silica and alumina, and in the latter equals it.

3. *Natural cement* is produced from stones containing from 40 to 60 per cent. of silicates, does not slack, and hardens rapidly under water. It is produced from stones containing enough silicates to exactly combine with the bases of the carbonates (after the carbonic acid has been expelled) to produce a hard compound with the silica and alumina as a whole.

From experiments, the best proportions before burning should be found as follows:—

2 equivalents of CaO CO ²	50.0 × 2 = 100.00	
1 " " clay, of which the probable composition is 1 equivalent of alumina . . .	51.5	
6 equivalents of silica	228.0	
	<hr/>	279.50
		<hr/>
		379.50

So that the composition in 100 parts is of—

CaO CO ²	26.35
Clay	73.65
	<hr/>
	100.00

The rapidity with which it hardens under water is in accordance with its proximity to these proportions.

When the stone of the above composition is burned and prepared, it is a mixture of *quicklime* and *silicate of alumina*; as soon as it is mixed into a paste with water a double silicate of alumina and lime is formed of the following apparent formula:—

2 equivalents of lime (CaO)	28.0 × 2 = 56.00
1 " " alumina	51.50
6 " " silica	38.0 × 6 228.00
	<hr/>
	335.50

and this double silicate forms the artificial stone.

Artificial Cement is formed by taking ground chalk, or slacked pure lime, and blue clay in the above proportions, thoroughly mixing with water in a mill, "batting" into two or three inch balls, drying, calcining, and grinding them to powder; it is equal, if not superior, to any natural cement.

4. *Puzzolanas* are mixtures analogous to cements, but wherein the silicates are in excess, and carbonates deficient; so that pure lime must be mixed with them to make hydraulic lime, or cement, according to proportions.

The best is "mine dust," which is sometimes obtained from some iron-tainted bituminous coals, or any silicate of protoxide of iron. If mixed with lime, so as to give the mortar a bluish-gray color, it becomes very hard.

Artificial puzzolanas may be made by grinding bricks, or by burning good brick clay and grinding it, or by any process yielding a good dry powder of silicate of alumina, or compound silicate of alumina and iron.

The above facts may subserve the purposes of furnace operations in many respects, inasmuch as it suggests a rapid, practical, and efficient method of valuing the limestones used as a flux, determining their value for the furnace alone, and also for the building and other purposes so frequently in course of execution about iron works.

Introductory to Dry Assay of Iron Ores.

When our only object is to separate, exactly, the amount of iron contained in a given specimen of ore, without regard to foreign matter, we apply the "dry method" in the assay of the ore. The philosophy of this operation is to deoxidize the oxide of iron, and produce at the same time a temperature sufficiently high to melt the reduced, or revived metal, as well as to melt the earthy material associated with the ores, together with any flux, if used. The former may be obtained in a dense button at the bottom of the crucible, and the latter in a liquid slag, or glass, above or attached to it. The foreign matter contained in the ore is silex, lime, clay, &c., as shown already in previous pages. As we have seen, these are, in themselves, very refractory; hence some flux is necessary to bring about their fusion. Fluxes generally employed in operating in a very accurate method are borax, quartz, or fine flint-glass, caustic lime, or, what are the best of all, carbonates of the alkalies. In these assays, as well as in large operations, we are guided by the chemical or elective affinities of the materials used or mixed with the ores, which affinities are spoken of in the first chapter. We must mix alkalies with clay, or with silicious ores, and acids with calcareous ores. Nevertheless, borax (biborate of soda and water) in almost all cases will reduce the foreign matter into a slag, being both acid and alkaline in effect.

In dry assay the button contains carbon, frequently silicon, phosphorus, sulphur, manganese, &c., according to the nature of the ore; and these may range from 3 to 5 per cent. or more, and therefore the iron may weigh more and yield a higher per cent. than in the wet assay; yet it approaches nearer to the smelting qualities and quantity on the large scale.

1. *Assays with Charcoal*.—We use either lined or unlined crucibles. In the charcoal-lined (called *brasqued*) crucible the oxide of iron in the ore is reduced by the lining of charcoal, or by the CO which, at high temperature, is evolved. If the flux is properly adjusted, the iron will contain the maximum of carbon, and the slag be practically free from iron.

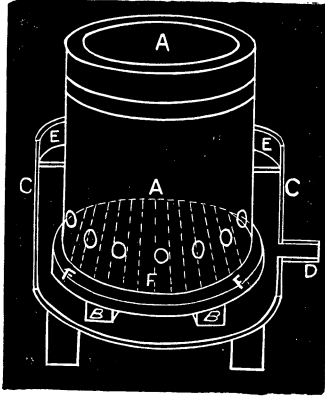
In the unlined crucible a sufficient amount of carbon is sometimes recommended to be mixed with the ore; but this is not advisable, as the carbon, when mixed with the fine ore, may prevent the segregation and the sinking of the metal. The slags generally contain some iron, although the button approximates, in per cent., that of the wet assay. Before we proceed, it may be better to look to the nature and efficiency of our assay furnaces. These may derive their blast from the draft of the chimney alone, or from a blower, or bellows.

The efficiency of the air furnace must depend upon the draft. A good furnace must be capable of heating to a white heat. The furnace should be lined with fire brick, whatever the outer lining may be. The furnace must be provided with a clay-lined top, else the heat of cast iron will be sufficient to prove a great annoyance. The smoother and cleaner the shaft and the higher and straighter the ascent, to a certain limit, the finer the draft will be.

We have adopted the plan of a furnace in which, with the aid of a moderate blast from an ordinary bellows, we can reduce any ordinary ore assay of from 10 to 200 grains in from ten to twenty minutes after the crucible is heated. A A represents an ordinary fire-clay cylinder, used in some coal stoves, and obtained at any large stove dealers; diameter of the one in our

laboratory, 12 inches—height about 14 inches; C C a sheet iron cylindrical case—an air pipe at D, with a bottom but no top, excepting a broad ring at E E below the edge of the cylinder, forming a gutter into which

Fig. 15.



damp clay may be put to tighten the fit of the fire-clay cylinder A A as it slips down into the hole and rests upon the soapstone, or fire-clay bottom F F F, which itself rests upon the bricks B B. The whole affair need not cost \$6, and the clay cylinder be banded with hoop-iron, or, better, sheet iron. It forms a Sefströms blast furnace of a very simple and serviceable kind. The air enters at D, is confined in the cylinder until it enters the holes, which are generally already in the clay cylinder before purchased, and are sufficient for the purpose, both as to size and number—else for this size, we find that six holes, $\frac{3}{8}$ inch diam. are sufficient, and they may be made with a file, accordingly. The furnace should be placed upon a brick hearth or supports. Coke, charcoal, or anthracite, in pieces—size of an egg—burn well after kindling. The furnace should be heated very slowly at the first heat, and cautiously afterwards. A conical top of heavy sheet iron ($\frac{1}{8}$ inch thickness), with a pipe at least five inches diam., to lead off the smoke, is advisable, and, as this gets very hot, it is rimmed or flanged inward on the lower edge with an

inch rim all around, to hold up a clay lining on the inside; but thick sheet iron serves by itself, with exception that it throws out much heat. The use of a small size blacksmith bellows with nozzle connected by even a leathern hose, or tin pipe, allows the furnace to be placed at a distance under a hood leading to a chimney, or under the chimney itself, and the operator may be at a comfortable distance.

The crucible is usually placed upon a small brick "bat," or, when the coal is firm, no stand is needed, but the crucible may be put into the coal firmly in place, and after a little heating without blast, the blast may gradually be put on. This, we think, is the most practicable form of furnace, of the assay-blast-form that can be put, cheaply and serviceably, together. An improvement may be made by putting one or two blast holes in the soapstone base so that the coal may be more uniformly ignited. Instead of a cylinder of one piece, one of several pieces, banded, is less liable to crack, and for that reason, only, is preferable.

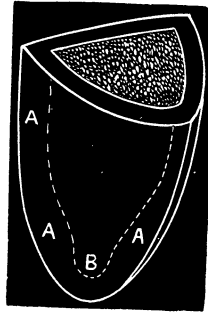
For an air furnace care should be taken that the smoke stack is smooth inside, straight, and as nearly as possible perpendicular, and of sufficient height (from 30 to 45 ft. for a fine draft). They should be round to insure the best form, as corners occasion obstruction to the current and are unequally heated. When neither of the above furnaces can be had, a common blacksmith's forge may be resorted to with tolerable success. Whatever the kind of furnace, the crucibles must be prepared as follows:—

The high temperature at which iron ores are to be assayed requires that the material be of the most refractory nature. In some cases the common Hessian crucible may answer. In others plumbago, or blacklead, must be used, and in some cases the finer clay of the French crucible.

The properly sized crucible having been taken, line the interior with charcoal powdered and mixed with water, or water and molasses, or molasses alone, previously well mixed with the coal and the latter thoroughly

trituated into the mass in a mortar. It may be rammed in so damp that it will adhere, and with a wooden pestle which may form the mould of the cavity. It is best to line in successive layers smoothly, put in one upon the other, as by this means a more adherent mass and a complete mould are obtained than when the whole mass is put in at once. The lining should not be less than $\frac{1}{4}$ inch thick, and the form is the best when made something similar to the following: A A A charcoal lining, B cavity, generally preferred, the small lower contracted department being that in which the ore is deposited. If the furnace has iron bars at the bottom—or an iron plate—it is always advisable to put the crucible upon half of a fire-clay brick, rubbing the top with a little plumbago to prevent adhesion of the crucible, and disposing it so that the crucible may be very nearly within the hottest part of the furnace. Should the heat be so great as to soften the crucible, care must be taken to let the temperature of the furnace decrease, so that the crucible may regain its hardness to some degree, before it is removed.

Fig. 16.



Percy recommends for crucibles, a mixture of about 2 parts unburnt to 1 of burnt fire clay, of good quality—5 lbs., avoirdupois, of unburnt clay to 2 lbs. of burnt clay, called “grog,” will make about $6\frac{1}{2}$ dozen crucibles and 2 dozen covers. The waste scraps do for covers.

Four parts, by weight, of charcoal powder to one of molasses, “treacle,” is a good mixture for lining—13 ozs., avoirdupois, charcoal powder and $3\frac{1}{2}$ ozs. treacle will line about four dozen crucibles. It should be beaten till it is fine and adheres, without lumps, to the fingers.

After lining, the crucibles should be dried, and then placed in a muffle, or some other hot place, and heated till vapor, smoke, and flame cease to appear around the mouth covered with the crucible cover. They are then

taken out and cooled. The lining should be without cracks, solid, smooth, of close texture. The covers for brasqued crucibles may be formed out of ordinary lumps of charcoal fitted by means of a saw, knife, or rasp.

The fuel may be charcoal, coke, or anthracite;—of this, choice must be left to the assayer; charcoal burns out more rapidly, but is purer and freer from sulphur, which, in some instances, may, through oversight, be admixed. Coke and anthracite may be mixed, broken into pieces not less than an inch in size if used in the Sefström furnace of the kind described.

Caution.—A reduction of the sample may be made with much less care than that indicated already; but if the assayer intends to be accurate, particular attention must be paid to the exceeding fineness of his charcoal, the compactness of the lining and smoothness of the surface, else his assays when delicate, will be sure to vary much and cause great annoyance.

Another method of reduction of ores may be adopted, though on any large scale it is expensive, but can be tried as a corroborative test. Mix the powdered and calcined ore with cyanide of potassium, and then proceed as above. This mixture never fails to furnish, by a low temperature, a button of gray metal.

Assays with Fluxes.—Fluxes for Assaying.

Silica.—White quartz; rock crystal plunged while red hot into water and afterwards powdered is preferred as purest.

White sand, truly silicious, or powdered flints may be used.

The assayer must examine his sand with a microscope, for all sand is not silex, and unless that be the case, the proportions given will not apply. Some river sands contain much alumina, and even lime, and little, comparatively, pure silica. This flux is used when the ore is deficient in silica.

Glass.—Plate, crown, and window glass heated red

hot and quenched in water, as above directed, is used. It contains 60 to 70 per cent. silica, the remainder is lime, potash, &c., and being fusible, it serves a good purpose in place of silica and silicate of alumina. It is used in nice assays only.

Green bottle glass contains oxide of iron, and flint glass protoxide of lead, and on that account only they are objectionable.

China Clay.—Is hydrated silicate of alumina, and forms a pure and useful flux; practically free from oxide of iron, if dehydrated it should be powdered and heated to redness, or else it will be in lumps. Of course in these latter two, the proportion of alumina, potash, &c., must be remembered if we would be very accurate in analysis of the slags, as neither is silex, or alumina alone.

Shale.—It is silicate of alumina and is sometimes used, as we have said, on a large scale, as a flux in blast furnaces; it makes a good flux in admixture with lime; contains iron, sometimes from 2 to 5 per cent., which is objectionable in assays unless you know the exact amount of iron, and, even then, because of the effect upon the color of the slag.

Fire Clay.—Hydrated silicate of alumina; is a good flux when mixed with lime; may be used in place of shale; contains iron from one to seven per cent., hence objectionable, unless white, and when it burns white and not red, or brown, the latter being the sign of iron.

Good Blast Furnace Cinder.—Silicate of alumina and lime; choose the white, gray, and nearly colorless; glassy varieties especially should be sought for. When powdered, it is good for ores free from gangue,* or which do not contain much silica.

Borax Glass.—By itself it is too fusible for iron assays, as it combines with the oxide of iron at a low temperature, and before reduction occurs. When used, the proportion of lime should be increased to render it less fusible. Borax heated until the water of crystallization

* Any associated rock or substance clinging to the ore and not partaking of the ore-nature.

is driven off, is the glass spoken of. Pulverized common borax swells up so much as to disturb the assay.

Lime.—Common powdered, *unslaked* lime should be used; but limestone, chalk, or any varieties of carbonate of lime may be substituted, if the CO^2 in combination, is accounted for.

Carbonate of lime contains 56 per cent. lime and 44 per cent. carbonic acid; 100 parts lime are equivalent to $178\frac{1}{2}$ parts carbonate of lime.

Care should be exercised to see that the carbonate of lime is free from *sulphate*, silica, magnesia, &c., if correct information, as to results, is expected.

Fluor Spar, or Fluoride of Calcium.—White varieties should be selected; the presence of quartz not objectionable; should be free from metalliferous minerals; forms useful compounds with silica and silicates.

One hundred parts of fluor equivalent to seventy-two parts lime; it may replace lime, very favorably, in case the assay has much silica.

Cryolite.—Fluoride of alumina and soda is preferable to the last, and acts much as that flux does. The composition has already been given under Iron and Aluminum. Pure white specimens should be used, but the action of either of these fluxes is injurious upon some crucibles, because of causes already mentioned in the place just alluded to.

The Main Object of Fluxes.—As we have seen, in all operations involving their use, it is the formation of easily smelting slags composed of those materials in the ore which are not oxides of iron. Now, practice has determined that, generally, the most easily fusible ores are those in which the carbonates of earths (lime and magnesia) as one class, and the clayey and silicious matters as another class, are in the general ratio of two to three. *The point to determine, then, is the deviation* from this ratio in any particular case under consideration. The deficiency in the clayey, or argillaceous elements can be made up by china clay and the defects of carbonates of earths by chalk, oyster shells, and caustic lime.

A kind of general approximation to the character of

the ore is sometimes obtained by submitting a portion to the action of muriatic acid in a test tube. The amount of effervescence may in some measure determine the relative amount of carbonate, but as we may suppose, from what has been already said, this should be received with some qualifications, which the judgment of the assayer, after one or two trials, will decide, especially by comparison of the effervescence of good marble with that of other specimens.

The Quantity of Ore to be Used, in either lined or unlined crucibles, depends upon the means you possess of raising the temperature; upon the size of furnace you use, and the character and delicacy of your balance. With a Sefström of the usual size and a good assaying balance, weighing $\frac{1}{100}$ of a grain, 20 grains may be used, and 200 grains is generally the highest amount to be assayed with advantage at any one time. In brasqued crucible the whole amount, whatever it be, is put in the crucible-chamber, the crucible filled with charcoal and covered, luted well and then exposed to heat. At first, gentle and gradually elevated temperature should be used, until all the gases have escaped and the crucible heated through thoroughly, and then the highest heat may be brought to bear upon the crucible. In a good air furnace, from one-half hour to one hour is sufficient; but, in a furnace of poor draft, three to four hours may be required. The crucible is then removed and cooled, the button taken out, cleaned, and weighed. The button will be found lying under a mass of vitreous slag, or the slag attached to the button, at the bottom of the crucible. The quality of the button is first tested by being struck on an anvil under a hammer. If it flattens under the hammer, the iron promises well; if it breaks, it approaches a cast iron which, under the present circumstances of reduction, especially under charcoal, offers little promise of good metal when smelted on the large scale.

These last remarks are somewhat to be qualified in what shall be hereafter said.

The assay in this method is always more satisfactory

if the ore is calcined, or heated to a low red heat before committed to the crucible. The weight lost by calcining must be entered into the calculation, if the ore was in its saleable state at time of beginning the assay.

Choosing Samples.

Several pounds weight should be taken of the ore to be assayed and broken down on an iron or quartz slab or surface, and, from this quantity, average specimens, to the amount of one-fourth of the whole should be selected and broken into coarse powder, and so treated as to form a fair average by spreading out uniformly and dividing into four parts, taking diagonally opposite quarters—this is, properly, sampling. Percy recommends a wedgewood mortar and not iron, in which to reduce the ore to fine powder. It is not necessary in crucible assays of this kind. A good, square, steel-capped anvil, surrounded with paper, will serve as good a purpose as may be desired. A fine steel mortar is better if it can be had. Pass the powder through a sieve of from 40 to even 80 holes to the linear inch, according to character of the ore and assay, the heat of your furnace, and the quantity taken.

The ore need not be powdered any finer than would permit it to pass a miller's bolting cloth of fineness equal to 40 to the inch if it is to be reduced in a brasqued crucible, and if the ore is a hematite of usual character. Ores of more difficult fusibility must pass through 60, and some red hematites and magnetic through still finer holes. The ore may be dried at about $110^{\circ}\text{C.} = 230^{\circ}\text{Fah.}$ As we have said, ores contain sometimes hygroscopic and combined water, and therefore must be dried accordingly, moist ores at boiling water heat, or somewhat less, in the open air, and then sampled and weighed; hydrated ores, or those with combined water, only need be dried in the crucible after weighing. When ready for the crucible they should be intimately mixed with the flux, if to be assayed with fluxes. If to be assayed with charcoal, it

is advisable not to mix them, as we have said in a previous place.

Proportion of Fluxes.

The flux varies according to the nature and amount of gangue mechanically attached to the ore, and that material in the ore not oxide of iron, together with the quantity taken and the size of crucible. That flux which will just take up all the gangue and impurities and nothing more, and at the easiest point of fusion, all things considered, is the proper proportion.

Blast furnace cinder of the following type is considered desirable: Al^2O^3 , $\text{SiO}^3 + 2(3\text{CaO}, \text{SiO}^3)$.

The approximate composition per cent. is:—

Silica, 38	}	or about	2½ parts.
Alumina, 15			1 “
Lime, 47			3 “

and this may be considered the theoretic type of good slag.

The following mixtures of various fluxes, when fused, produce a slag which is considered as approximating the above proportions. (Percy).

Quartz 1	{	Silica 0.92	1.92	}	= {	36.5 per cent.
China clay 2 =						
Lime 2½						
Glass 2½	{	Silica 1.75	2.5	}	= {	35 “
Lime 2½						
Shale or fire clay 3						
Lime 2½	{	Alumina 0.9	2.5	}	= {	17 “

If the composition of the ore is known, it is easy to ascertain the amount of fluxes necessary to form a slag with the bases present in the ore. When necessary, an extra amount may be used to cover the button.

* *i. e.*, 30 per cent. of alkalies, lime, etc., on account of its fusibility, are taken as equivalent to so much alumina.

Example: the ore is chiefly carbonate of protoxide of iron.

	10 grs. of the ore contain	Add proportion wanted.	Add to increase bulk.	Fluxes taken. Total.
Silica	0.86	Sand 1 gr. +	$\frac{1}{2}$ gr.	= $1\frac{1}{2}$ gr.
Alumina	0.79	0 gr. + china clay	1 gr.	= 1 gr.
Lime, magnesia, and other bases	1.30	Lime $1\frac{1}{2}$ gr. +	$1\frac{1}{4}$ gr.	= $2\frac{1}{2}$ grs.

In practice, analysis is not resorted to to find what amount of bases are present. Experience brings all the aid generally necessary to adjust proportions.

In case of doubt the following may be a preliminary trial :—

	Parts by weight.	Parts by weight.	Parts by weight.
Glass	4	$2\frac{1}{2}$	1
Lime	$1\frac{1}{2}$	$2\frac{1}{2}$	4

The three trials may be made at the same time in three crucibles. Mixtures of clay and lime may be substituted for the above.

The following assay classification of ores and metallurgical products and the proportions of fluxes which have answered in practice, may be found useful, ten grains being the quantity taken.

1. Ore free from gangue, or nearly so, *e.g.*, magnetite, red and brown hematite, specular iron ore, micaceous iron ore:—

Glass	$2\frac{1}{2}$ to 2	Sand	1 to 0
Lime	$2\frac{1}{2}$ to 3	China clay	2
		Lime	$2\frac{1}{2}$

or, separately of

Blast furnace cinder	5
Fluor spar	5

2. Ores containing silica, varieties of brown iron ore, refinery, tap, and flue cinders:—

Glass	1	China clay	2
Lime	4	Lime	4

3. Ores containing carbonate of lime, magnesia, protoxide of manganese, etc. Calcareous hematite, spathic iron ore.

Glass	4 to 3	Sand	1
Lime	$1\frac{1}{2}$ to 2	China clay	2
		Lime	$1\frac{1}{2}$

4. Ores containing silica and alumina, clay iron ore.

Glass . .	$2\frac{1}{2}$ to 0	China clay	0 to 2
Lime . .	$2\frac{1}{2}$ to 3	Lime . .	2 to 3

With ten grains, the balance should turn to $\frac{1}{50}$ grain. If the assay be for 100 grains, a balance turning from $\frac{1}{5}$ to $\frac{1}{10}$ of grain will answer. The mixed flux might be added till equal to $\frac{1}{2}$ the weight of the ore used. (*Percy.*)

The principle of procedure is as follows when the composition of the ore is known: Supply the parts of the type-slag given above by adding those ingredients lacking in the ore, in the proportion to make the type-proportions. For instance, the type is Silex 38, Al. 15, Lime 47. If the ore contains those *elements* in the same order, but in *quantities*, as 30, 10, 40, it is plain that 8, 5, 7 parts are to be added to make 38, 15, 47. If no Al. had existed, or lime, in the ore, then the proportions would have been 8, 15, 47. But, if the ore contained more of any one ingredient than in that of the type, there is an apparent difficulty, easily overcome, however, thus: Ore = Silex 50, Al. 15, L. 47. Now, Si. 50 is 12 parts too much for the remaining proportions. Treat the 12 parts, then, to its proportion of Al. and Lime by the natural proportion, first for Al., thus, as 38: 15 of the type so is 50 to 19 of the ore; then it will be plain that 50 parts of Si. demand 19 of Al. Next find the L. As 38: 47 :: 50: 61, then the flux to be applied will be Si. 50, Al. 19, Lime 61, but there are Al. 15 and L. 47 already in the ore, therefore subtract them from your newly-found proportion, and it will give, to be added from outside of the material already in the ore, as follows: Al. 4, L. 14, because these quantities of Al. and of Lime bear the same proportion to 12 of silex over and above in the ore, that Al. 15, Lime 47, did to 38 of silex. If all ingredients vary from the type proportion, then a computation must be made for each. This is an important type, and it may be approximately used in the furnace as well as in the crucible and the modifications, where care and judgment have been exercised, will trouble but very little. It will be seen that the

amount of iron in the ore causes but little alteration in the proportions, as it is the gangue and earths we wish to remove to obtain the metal.

Practical Directions for Assaying; Wet and Dry Methods.

In Air Furnace.—The powdered ore is intimately mixed with the fluxes. Mix on glazed paper, or in agate mortar, and carefully introduce it into the cavity if a brasqued crucible is used; close up with a charcoal plug. Lute the top with clay, and adjust the brick upon the bars; build the fire about the clay brick; then, having fairly started it, the furnace is filled with fuel, closed, and the process carried on to a white heat. After sufficient time has elapsed, to be determined by experiment, the furnace is cooled down, the crucible removed, opened, and broken, if not brasqued, and the button removed, cleaned, and weighed.

The foregoing assays comprise what is called the “dry assay,” or crucible assay of ore. Allowance must always be made in weighing, for the amount of carbon combined with the metal button, and also for any sulphur, silica, &c., which it may derive from the ore and the charcoal, or flux used. But the metal approximates, in nature and quantity to that which the blast furnace would produce on the large scale. The impurities, inclusive of carbon, may amount to as much as six per cent. In attempts to get the amount of cast iron, per ton, that any ore would yield, this assay is better than the chemical, or wet method, and the button resulting is in a proper state for a fine analysis in the wet way.

Hessian crucibles, ordinarily sold at the shops, will generally answer for iron assays, by brasquing, and even when fluxes are used without charcoal, but care must be taken to heat them up to the reduction point of the ore, gradually, and to allow them to cool somewhat before taking them out. It is always advisable to rub the outside with plumbago (black lead) to prevent the cinders, brick, &c., from adhering, and even with fluxes the same rubbing inside may be as good, except where all

carbon must be avoided, and then the French crucibles are better, being of a finer, purer clay. Plumbago crucibles stand more heat, but will impart carbon to the assay.

As it is sometimes desirable to obtain the absolute per cent. of pure iron an ore contains, we shall now describe the readiest methods known in analysis.

THE WET ASSAY—1. *By Volumetric Assay.*

By Bichromate of Potash.—Three hundred and five grains, dried and pulverized, crystallized bichromate to four pints (35,000 grains) distilled water are equivalent to one thousand grains of a solution, which will answer to ten grains of iron on the following method:—

Its action depends upon the fact, that an acid solution of a protosalt of iron is reduced to the persalt by a solution containing chromic acid, with the formation of a sesquisalt of chromium.

A solution of ferricyanide of potassium is used, dropped upon a white plate, to determine the time when the protosalt is converted into persalt, as it will cease to cause a blue color when the change occurs. The ore is dissolved in HCl, or SO^3 , and converted into a protosalt by dropping in pure zinc and boiling, care being taken to have no particles of zinc come over from the boiled solution of ore and zinc after the latter has accomplished its office and should be separated for volumetric assay. If sulphite of soda is used, it may be taken crystallized or in solution kept for the purpose, but exposure to air ruins it. Care should be taken that no sulphurous acid remains after using the sulphite of soda; this can be avoided by boiling till no sulphurous fumes come off; a little zinc dropped in will give off HS if SO^2 remains. When the conversion of protosalt to persalt has taken place, or is about to take place, the assay solution assumes a greenish cast; if it assumes a reddish-yellow, enough hydrochloric acid was not used; add it, therefore, and proceed. Shake the bottle containing the standardized solution before using.

The test solution of ferricyanide should be made of two to five grains salt to one-half pint of distilled water.

The solution may be standardized by three solutions of fine iron wire in hydrochloric acid, or sulphuric acid, and it may be dissolved clear and without the straw-colored appearance, by expelling the air from the hydrochloric acid by boiling and then dropping in the coil of wire and boiling till it is dissolved and then removing the lamp. Having found out what amount of your solution is required to peroxidize a certain amount of wire-protosalt a simple proportion will determine any other amount. The assay solution need not be cool, nor does any foreign matter in the solution deteriorate the operation.

Permanganate of Potash is used also, but the protosalt solution must be cool for this reagent to act properly.

Process.—Ten to twenty grains of ore finely powdered are heated with strong hydrochloric acid for about twenty to thirty minutes, in a flask with a small funnel in the neck; when decomposition is complete, dilute with water, add a few pieces granulated zinc, and keep up ebullition till every trace of yellow color is removed and the solution becomes colorless, or a slight green tint remains; free it from fine particles of zinc; the flask is emptied into a dish, and care taken in rinsing that no particles of zinc come over. Then it is treated with permanganate as with the bichromate.

The permanganate of potash may be made thus: 8 parts of peroxide of manganese (Swedish), 10 parts of hydrate of potash (fused), and 7 parts of chlorate of potash, by weight, are to be mixed and heated to redness for one hour. The fused mass is treated with water and nitric acid, cautiously added, till the solution changes to a dark purple violet color, when it is filtered through a funnel containing asbestos, or coarsely powdered glass, or it may be decanted after settling. The residue may be used again.

200 grains of permanganate of potash crystals are to be dissolved in 4 pints of distilled water. The solution of iron prepared as before, is diluted to 2 pints with distilled water, in a white dish, or glass over white

paper, and the standardized solution slowly poured on and stirred till the faintest pink appears.

Sesquisulphate of iron has less coloring power than the sesquichloride, when the latter is in use, by adding sulphuric acid to the water before dilution of the sesquichloride the coloring is more distinctly seen.

The solution must be cool before being treated with the permanganate; but, as we have said, it is immaterial with bichromate.

Iron ores containing organic matter should be calcined, or the acid solution filtered off before adding the solution of permanganate. This, also, is not necessary when the bichromate is used.

The burette should be filled to the top division and through a glass stopcock in the tube, not an India rubber tube, be allowed to drop into the solution till the above effects result. With a little practice and care accurate results may always be expected.

THE WET ASSAY—2. *By Chemical Analysis.*

[If an assay of ore is to be made where not only the amount of iron, but the quantity and quality of the foreign matter are required, the operation becomes more complicated, and it is necessary to proceed still further. If we know nothing of the composition of the ore, and wish to determine the presence of every important substance besides iron, we proceed according to the following method: The iron ore, say one hundred grains, is powdered, and passed through a silken sieve, of fineness such as we have already indicated; it is then digested with water, and hot nitro-muriatic acid poured over it; this acid will dissolve everything but silex; and in many cases will even dissolve some silex, particularly in magnetic and calcareous ores. However, an excess of the acid generally prevents its solution along with the alkaline oxides. If the solution is completed by boiling, lime, magnesia, alumina, iron, manganese, &c., will probably be dissolved, and silex remain undissolved; this may be filtered, washed, dried, and weighed. Oxalate of am-

monia, added to a few drops of the solution, diluted with water, will indicate the presence of lime by precipitating oxalate of lime in a white powder. In the same way, magnesia may be detected by basic phosphate of soda, which precipitates phosphate of ammonia and magnesia, even in a very weak solution, by stirring it with a glass rod. In the concentrated acid solution, alumina may be detected by adding some sulphate of potash in powder, which dissolves or increases in bulk; in the latter case, it forms alum in crystals, which may be separated and dissolved in water. Caustic ammonia will precipitate alumina from this solution. Manganese cannot be detected until the iron is separated; this separation can be accomplished in the following manner: Dilute a few drops of the original solution with water, and precipitate the iron by means of a solution of galls; then filter; take the clear liquid, and precipitate by caustic potash, or soda: if manganese is present, a white precipitate falls, which alters its color by degrees into yellow, brown, and, finally, when exposed to the influence of the air, black. The presence of sulphur, or phosphorus cannot be ascertained in this way; but carbonic acid will rise in bubbles when the acid is poured over the ore; and if we intend to determine the amount of carbonic acid, the calcining of the ore powder is required before it is dissolved. The loss of weight in this operation, with due allowance for the alteration from protoxide to peroxide, will give the amount of water and carbonic acid. The foregoing manipulation will give the qualitative analysis of the ore; but if the quantity of matter in the ore composition is required, the following method must be pursued:

Take a mixture of caustic potash and caustic soda, each one hundred grains, and melt both together in a platinum, or better, a silver crucible; then throw in, by degrees, continually stirring, the one hundred grains of powdered ore. The alkali will dissolve silex, alumina, the sulphurets, and phosphurets, and leave oxide of iron, manganese, lime, and magnesia undissolved. The aqueous solution may be filtered, and the residue dissolved

in strong sulphuric acid, which dissolves the oxide of iron, magnesia, and manganese. Lime is left as a white powder, which is sulphate of lime, *gypsum*. From the acid solution, magnesia may be precipitated by basic phosphate of ammonia; the sediment, washed and calcined, leaves phosphate of magnesia. The remainder of the acid solution contains iron and manganese, which are to be separated by gallic, or succinic acid, which precipitates the iron. This sediment may be ignited, leaving peroxide of iron. The manganese is to be precipitated by caustic potash, or soda; filtered, and dried. In this way we get the amount of iron in oxide of iron; the manganese; magnesia in phosphate of magnesia; and the lime in sulphate of lime. The alkaline solutions of silex and alumina are to be saturated with sulphuric acid, which precipitates the silex in a white powder; this is to be washed and dried. The remaining alumina is yet held in solution, and may be precipitated, after neutralizing first with solution of caustic potash, by carbonate of ammonia. If sulphur is in the ore, it may be detected by the smell of sulphuretted hydrogen, when pouring the acid on the alkaline solution, or may be previously tested by acetate of lead. Phosphorus may be detected by letting fall a few drops of the alkaline solution into some lime-water, when phosphate of lime is precipitated, provided there is no carbonic acid present; this can be ascertained by testing the white precipitate by hydrochloric acid, which dissolves the carbonate of lime, but not the phosphate, if there is no excess of acid.

A quantitative chemical analysis may be seldom insisted upon by the iron manufacturer, and is not generally considered to be actually needed. This may be, in some measure, true; but a qualitative analysis is almost necessary in every case. A good manager should be able to determine at least the quality of the matter of which his ore is composed. An analysis of this kind is very easily effected; and we shall describe a simple method by which the component parts of any kind of iron ores may be discovered.

Iron ores are of various colors, and occur in the most various forms. The following is the most simple test by which a given specimen of mineral may be determined: Put it into a slow burning fire—say a common grate fire—and there leave it for twenty-four hours. If, at the expiration of that period, it shall have turned red or brown, it may be considered iron ore. We may also conclude that it is iron ore when, in turning black, some fragments of it are attracted by the magnet. If the substance shall have turned white, it will be either wholly or in greater part lime; which, however, may be very useful under circumstances where calcareous ore is needed. This is an easy practical method of arriving at an estimate of a mineral species; but, with the exception of the iron it contains, leaves us quite in the dark as to its component parts. If any specimen is proved to contain iron in sufficient quantity to justify the manufacturer in smelting it, it is of great consequence to know the foreign matter associated with it. To determine this point we proceed as follows:—

Sulphur exists in most iron ores, particularly the hydrates, either in the form of sulphates, or sulphurets. To find sulphur, a portion of ore is pounded and passed through a fine silk sieve of 50 to the inch, and then washed with a large quantity of rain water, which must be previously proved to be free from sulphuric acid by the fact that no precipitation occurs on adding a drop of a solution of chloride of barium. The wash-water of the powder, which may be boiled with the ore, is set to rest, that the iron may subside; and part of it is then tested with chloride of barium. If a white precipitate falls, we may conclude that the ore contains sulphuric acid. In some ores, particularly the yellow hydrates, sulphuric acid is not so readily detected. In such cases we must dry the washed powder, and expose it to a gentle heat until it reddens, and again pour it into the water. If, after this, it shows no signs of a precipitate with chloride of barium, we may conclude that no sulphuric acid is present. *Chlorine* is found in the same way, with the only difference that we use solution of

nitrate of silver as a precipitant. If a white precipitate falls directly, we may expect that the ore contains a large amount of chlorine. But a small quantity of chlorine will manifest itself only after one or two days' exposure of the solution to light, when it will gradually darken from violet to black. We may expect to find sulphuric acid and chlorine in the hydrates of the coal formation. Sulphur, in the form of sulphurets, may be detected by boiling the powder of iron ore in a solution of potash, which dissolves the sulphurets; and by testing that solution, when clear, with acetate of lead. If there is any sulphur in the ore, a black precipitate of sulphuret of lead will form directly.

The powder of ore, thus freed from sulphuric acid, chlorine, and sulphur, may now be dissolved in hydrochloric acid; this acid will dissolve everything but sulphate of baryta, sulphate of lime, silex, and carbon. Carbonic acid will escape with effervescence, and is easily detected, if present in any considerable quantity. If the insoluble residue is white, we may expect in it sulphate of baryta, silex, and a little alumina. The residue may be melted; fused with four times its weight of a mixture of carbonate of potash and soda, in a silver or polished iron crucible; soaked in water, boiled, and filtered; and then saturated with hydrochloric acid. If a precipitate falls, it is silex; while the remaining portion of the dissolved residue must be sulphate of baryta. Reagents may now be employed to test the first hydrochloric solution. The application of oxalate of ammonia to a few drops of this solution, largely diluted with water, will show the presence of lime; and caustic, or carbonate of ammonia, that of alumina. Sulphuric acid will precipitate barytes and lead. A bright iron wire, or blade of a knife, held in the solution for a short time, will show the presence of copper, by giving a coating of copper to the polished iron. Magnesia it is somewhat difficult to detect; but if it is not in too small amount, it may be detected by boiling the solution, from which baryta and lime have, by the above tests, been previously removed, with carbonate of soda; but more effectually, if we pre-

precipitate all the substances in a part of the solution by carbonate of ammonia, and remove the baryta by sulphuric acid, and the lime by oxalate of ammonia, neutralize by ammonia, and then precipitate by phosphate of soda, which throws down a basic phosphate of ammonia and magnesia. Acetate of lead is a very valuable reagent; it forms with any of the chromic solutions a yellow precipitate; with phosphoric acid a white, and with sulphur a black precipitate; but with a hydrochloric solution it would form a white sediment of chloride of lead soluble in excess of potash; while the sulphuret, chromate, and phosphuret are insoluble in that menstruum. If there is any zinc in the ore, it may be found, after the iron is precipitated, by sulphuretted hydrogen, provided the solution is previously neutralized; this precipitates a white sulphuret of zinc. For the purpose of detecting zinc, it is necessary to remove iron and everything else, by saturating the acid solution by ammonia, and by then testing with sulphuretted hydrogen. The most common compounds in iron ore are yet left to be found; these are manganese and phosphorus. Manganese is with difficulty separated from iron; and to effect this separation we recommend the solution of the iron ore in hydrochloric instead of nitrohydrochloric acid, because in the latter case the salts of manganese are very apt to oxidize more highly than protoxide, and are then inseparable from iron. If the solution of the ore is acidulous, the manganese will be in the form of protochloride of manganese, and may be separated from the iron by boiling the solution to dryness, and by expelling all the superfluous acid. On redissolving it in water, only the salts of alkaline and alkaline earths will be dissolved along with the manganese, and very little of the iron; this iron may be precipitated by succinic, or benzoic acid, provided the solution is neutral. After this we may detect iron by means of ferrocyanide of potassium, which, if the iron is all removed, ought not to change the color of the solution, but form a white precipitate with manganese. In a solution free from iron, the manganese will be precipi-

tated by ammonia or carbonate of ammonia, which throws down a double salt of manganese and ammonia. For the same reason as that given above we recommend the solvent hydrochloric acid, in an iron ore analysis, as the means of detecting phosphorus. The hydrochloric solution of iron, &c., may be neutralized by ammonia, which separates the earths and a part of the iron, but leaves the phosphates in solution. The solution may be tested by chloride of barium, which produces in a neutral or alkaline solution a white precipitate of phosphate of barytes; this is redissolved by adding hydrochloric, or nitric acid.

Those acquainted with the use of the blowpipe are able to detect sulphur, phosphorus, arsenic, zinc, and other substances, more easily with that instrument than by any other means. (Appendix A.)

Poor ores, especially clay ores, are sometimes difficult of assay in the dry way, even though we simply want to know the amount of iron contained in them. The clay ores require an uncommon amount of alkaline flux, and lime is not sufficiently strong to flux the alumina; we are therefore compelled to make use of potash, or soda. Both are very apt to perforate the crucible. A mixture of potash and borax answers better; but if too small a portion is used, all the iron is not revived; and if too much, the crucible is destroyed before iron begins to melt. In such cases, the best plan is that prescribed by Fresenius, that is, to mix the powdered and calcined ore with cyanide of potassium, and to smelt the ore, and revive the iron, in a porcelain or platinum crucible, over a spirit-lamp, in which case an excess of the flux is of but little danger. This mode of analyzing is particularly useful where arsenic is combined with the ore, for it will reduce the oxides of that metal in the most easy way. The arsenic may be separated before melting the iron; or, if more arsenic is present than that required to form an arseniate of iron, it may be evaporated by heating to ignition in a German, or hard glass tube. Otherwise, the latter compound will remain in the crucible.

For special methods, and more complete analysis, see Appendix F.

CHAPTER V.

FUEL.

Remarks.—It does not belong to our department to consider the many substances used to produce artificial heat. Of these chemistry treats. We shall speak of those vegetables and minerals alone which afford proper fuel for the manufacture of iron.

Wood.

Wood, in its raw state, does not constitute an available fuel, because it contains a large amount of water. This water contains more or less soluble minerals, and is called *sap*. By drying wood, a great part, but not all, of this water is evaporated. If wood is dried in a closed vessel, and then exposed to the atmosphere, it quickly absorbs moisture; but the moisture thus absorbed is much less than the wood originally contained.

a. The amount of water varies in different kinds of wood, and also varies according to the season. Wood cut in the month of April contains from 10 to 20 per cent. more water than that cut in the month of January.

The following table shows the percentage of water in different kinds of wood, dried, as far as possible, in the air:—

Beech	18.6	Pine, white	37.0
Poplar	26.0	Chestnut	38.2
Sugar, and common Maple	27.0	Pine, red	39.0
Ash	28.0	Pine, white	45.5
Birch	30.0	Linden	47.1
Oak, red	34.7	Poplar, Ital. . . .	48.2
Oak, white	35.5	Poplar, black	51.8

Wood, cut during the months of December and January, is not only more solid, but it will dry faster, than at

any other period of the year, because the sap by that time has incorporated a great part of its soluble matter with the woody fibre; what remains is merely water.

b. Hard and Soft Wood are terms which, for our purpose, have no useful application. The difference in chemical composition of the woody fibre, in most kinds of wood, is but slight, as the following analytical table shows:—

	Carbon.	Hydrogen.	Oxygen.
Sugar maple . . .	52.65	5.25	42.10
Oak	49.43	6.07	44.50
Poplar, black . . .	49.70	6.31	43.99
Pine	50.11	6.31	43.58

c. Of far greater importance to the manufacturer of iron is the *specific gravity* of the different kinds of wood. This is the proper criterion of their value, because wood is generally bought by measurement; and its specific gravity is directly in proportion to its amount of carbon, hydrogen, and oxygen; and the carbon and hydrogen constitute fuel. The following table shows the specific gravity of wood. Water=1.000:—

	Green.	Air-dried.	Kiln-dried.
Oak, white . . .	1.0754	0.7075	0.663
Oak, red . . .	1.0494	0.6777	0.663
Poplar	0.9859	0.4873	0.4464
Beech	0.9822	0.5907	0.5788
Sugar maple . .	0.9036	0.5440	0.6137
Birch	0.9012	0.6274	0.5699
Pine, red . . .	0.9121	0.5502	0.4205
Pine, white . .	0.8699	0.4716	0.3838
Ebony	"	1.2260	"
Guaiaac (lignum vitæ) "	"	1.3420	"

The value of wood by measure corresponds directly with its specific gravity after being dried in the kiln. Oak is, therefore, worth nearly as much again as white pine, for making charcoal. This subject deserves the close attention of the iron and steel master, for it is his business to select wood, and to regulate its price according to its quality.

d. Ashes.—The remains of wood after combustion,

denominated ashes, are of far greater importance than we would at first be inclined to believe. In the progress of this work, we shall find that the production of iron from the ore depends, in some measure, upon the quality and quantity of alkali present; and we shall further find that even the mechanical form of the alkali is of consequence in the reduction of the ore. It is, therefore, of no small importance to pay due attention to the composition of wood, in consideration of the amount and quality of ashes it contains. It is of more consequence to know the amount of fixed alkali in the ashes than the quantity of mineral acids, because the former always predominates in wood, while the latter is so insignificant that it may be neglected.] It has been supposed that it is due to the large amount of these alkalies in charcoal ashes, compared with the ash of stone coal, and its peculiar purity and combination, that the iron made from charcoal is superior to that from stone coal. [The alkali contained in wood is mostly potash, for soda is in so small a quantity, that it interferes very slightly in our calculations. We give the amount of potash contained in 1000 parts of wood of different kinds, cut during winter and dried:—

Pine or fir	0.45	Corn stalks	17.50
Poplar	0.75	Sunflower stalks	20.00
Beech	1.45	Thistles, in full growth	35.37
Oak	1.53	Straw of wheat, before }	47.00
Willow	2.85	earring }	
Maple	3.90	Wormwood	79.00
Dry beech bark	6.00		

Besides potash, a large amount of lime commonly exists in wood ashes. Lime is very favorable to the reduction of iron ores, and deserves attention. It is generally understood that the potash or soda which exists in the ashes of plants is always in an inverse proportion to the amount of lime they contain. We give, in the following analyses, a comparative view of the amount of lime in 100 parts of different vegetable ashes:—

	Beech.	Oak.	Pine.	Bark of Oak.
Carbonic acid	38.18	31.30	18.09	38.67
Sulphuric acid	1.19	0.90	3.75	0.37
Hydrochloric acid	0.85	0.62	0.00	0.04
Silicious acid (silex)	3.38	1.67	7.59	1.08
Phosphoric acid	4.77	6.27	0.90	
Potash	10.45	9.43	16.80	4.33
Lime	35.66	39.95	34.67	47.78
Magnesia	5.86	7.15	4.35	0.75
Oxide of iron	1.25	0.09	11.15	
Oxide of manganese	3.77	2.60	2.75	6.98

The amount of ashes differs in different plants, as the following table indicates, and varies strikingly in trees and shrubs, and in trunks and leaves. There are, in 100 parts of air-dried

Oak wood	{ old, 0.11	Pine wood	{ old, 0.15
	{ young, 0.15		{ young, 0.12
Birch wood	{ old, 0.30	Beech wood	{ old, 0.40
	{ young, 0.25		{ young, 0.37
Blackberry,	2.60	Wheat straw,	5.20

The amount, as well as the composition of ashes, depends, in a great measure, upon the composition of the soil in which the plant grows. But if the chemical composition of the soil is not able to furnish the vital component parts of a certain genus of plants, this genus will decay, and its place will be occupied by a class more appropriate to this composition. For this reason we often see oak growing where pine has been cut, and weeds spring up where none have been sown.

The ashes of a pine tree in one place, have contained

Potash	.	.	.	.	.	.	3.66
Lime	.	.	.	.	.	.	46.34
Magnesia	.	.	.	.	.	.	6.77

While ashes of the same kind of pine, growing in another spot, have furnished the following result:—

Potash	.	.	.	.	.	.	7.36
Lime	.	.	.	.	.	.	51.19
Magnesia	.	.	.	.	.	.	none.

e. Practical Remarks.—The foregoing investigations and tables are only designed to present to the iron or

steel manufacturer a comparative view of the relative values of wood. We have seen that there is a great difference in the specific gravity of wood; and that the price per cord should vary in accordance with this difference. Besides the attention which the specific gravity of wood demands, the consideration whether wood is old or young is very important. Young wood, saplings, if properly treated, generally produce a strong hard coal; old wood, when sound, is not inferior; but dead or decayed wood is useless for the making of charcoal, and it is imperfect fuel for any purpose. Therefore a higher price may be paid for young than for the same kind of old wood, when other circumstances are equal.

Every attention should be paid to the proper season for cutting wood. The worst time is from February until September. It should be cut and corded in October, November, December, and January; the best time is in the latter two months. Wood cut during winter, besides being ripe, will dry fast, and furnish a strong sound coal. Wood that is fresh and green is very apt to crack in charring, and produces a small porous coal, unfit for use in the blast furnace. Besides, economy recommends the use of the winter months, for then workmen are more abundant, and wood is twenty-five per cent. more valuable.

An acre, of 160 square rods, contains, on an average, thirty cords of wood; sometimes more, sometimes less. It requires excellent timber to produce forty cords; and only very close timber will exceed that. The best timber is always the cheapest, although it commands a higher price. There should be more than 500 cords in one coaling; else the business would be profitable neither to the colliers nor to the master.

Peat.

This mineral fuel, as yet, is of but little consequence to us, because where there is not abundance of wood there is stone coal; nevertheless, we will give it a cur-

sory notice on account of its chemical composition, which, to iron workers, is not without interest, because the question has been of late years considerably agitated as to the use of peat in iron operations. It has been found that peat is a most excellent fuel for the blacksmith's forge, as in case-hardening, tempering, and hardening steel, forging horse-shoes, and particularly in welding gun-barrels. For this purpose it is pressed and charred.

Peat is generally found in bogs, in horizontal layers from ten to thirty feet in thickness; sometimes in the form of a blackish-brown mud; sometimes it is a dark peaty mass, and often a combination of roots and stalks of plants; frequently the peat layers interchange with layers of sand or clay. Sea water is better adapted to the formation of peat than rain or spring water.

Peat is simply dug with spades, and then dried. If too moist to be dug, the half-fluid mass is piled upon a dry spot and there left until the water drains, and until the mass appears dry enough to be formed into square lumps in the form of bricks or rolls. In many instances, however, the freshly dug peat is triturated under revolving edge wheels, faced with iron plates perforated all over their surface; through the apertures in these plates the peat is pressed till it becomes a kind of pap; this pap is put into a hydraulic press, and squeezed until it loses the greater part of its moisture. It is then dried and charred in suitable ovens. The charcoal made in this way deserves the notice of the artisan.

a. Ashes.—The amount of ashes in peat varies greatly; and, economically considered, ashes are of considerable importance. Some specimens contain only one per cent., while others contain thirty per cent., which, in direct proportion, diminishes the value of peat. But it is not so much the quantity as the quality of these ashes which interests us. Their value as a fuel to the blacksmith is indicated by their chemical composition. It is a remarkable fact that, in peat ashes, we never find any carbonated minerals; while they contain phosphates, sulphates, and chlorides.

An analysis of peat ashes gave, in 100 parts,

Lime	15.25
Alumina	20.5
Oxide of iron	5.5
Silex	41.0
Phosphate of lime	15.0
Chloride of sodium	15.5
Sulphate of lime	21.0

In other kinds of peat, thirty-four per cent. of phosphate of lime, and six per cent. of chlorides, were found. The phosphates and chlorides have an excellent influence upon the hardening and welding of iron and steel; and if we use peat for these purposes, we should analytically investigate the composition of the ashes which it produces.

Though the elements of peat ashes are beneficial to the working of bar iron and steel, it does not follow that they are equally beneficial in reducing iron ore; for in the blast furnace phosphates of any kind are injurious, and produce a cold-short iron. Therefore we should be very cautious when we recommend peat for the blast furnace. We should recommend only such kinds of peat as contain neither too many phosphates, nor too great an amount of ashes; otherwise, we run the risk of producing bad work in the furnace. Dug peat, that is applicable for the smelting of iron, should never contain more than five per cent. of ashes.

b. Chemical Analysis of Peat.—The component parts of peat differ from those of wood. This difference is owing to the fact of its being decomposed woody fibre. We present an analysis of several specimens:—

One hundred parts of good peat contained, besides ashes,

	Carbon.	Hydrogen.	Oxygen.
No. I.	57.03	5.63	31.76
No. II.	58.09	6.93	31.37
No. III.	57.79	6.11	30.77

We find here less oxygen, but more combustible matter, than in wood.

c. Practical Remarks.—Peat is a very imperfect fuel,

because it generally contains too much foreign matter; and it is too expensive where wages are high. A great deal of it is used in different parts of Europe, where cheap labor and scarcity of wood and stone coal render it more available. But in this country there are few places where wood and stone coal cannot be had at reasonable prices, and, as yet, there is not much prospect of peat coming into use for the manufacture of iron. Still, it is unquestionably useful in working steel and bar iron. In such cases, however, it should be subjected to a chemical analysis. Peat should never be used in its raw form, but only when charred. Where its composition is shown to be favorable by chemical analysis, we need not be harassed in relation to its price, for its utility is so obvious that a liberal expenditure may be safely hazarded. The expense of peat, in comparison with that of wood or wood-charcoal, may be estimated by weight. The specific gravity of a cord of dry wood is from two to three thousand pounds; and, if we consider that air-dried wood contains from thirty to forty per cent. of water, the real amount of combustible matter in a cord is reduced from thirteen hundred to two thousand pounds. Air-dried peat always contains more or less water, and this is to be deducted before we can know its real value. The amount of water varies exceedingly, ranging from ten to forty per cent. It can be easily expelled by weighing the peat when fresh, then exposing it to a boiling heat (212°), and again weighing it. The difference is water. According to this, a ton of air-dried peat ought to be worth as much as a cord of wood, provided the quantity of ashes in the peat is not too great—say ten per cent. This quantity can be found by weighing a piece of peat, and burning it slowly on a plate of sheet iron, until all the carbon is expelled. This operation requires a red heat. The remainder is ashes. If peat is dug for the purpose of charring, it is advisable to employ a good strong peat press. Peat, thus pressed, chars excellently, and yields a charcoal as hard again as the best sugar maple, or hickory coal.

COAL.—*Lignite, or Brown, Bituminous, Anthracite.*

Coal may be conveniently divided into three distinct classes: The upper, or more recent geological deposit, is called lignite, or brown coal, distinguished by its color, which is mostly brown, and its texture, which is that of wood slightly charred. The second deposit of mineral coal, generally called bituminous, or stone coal, is geologically below the lignite. This coal is black, more or less of a vitreous lustre, containing bitumen varying from ten to sixty per cent., and called, accordingly, *dry* or *fat*. The third class in our arrangement is anthracite coal, characterized by its great hardness, and the small amount of hydrogen it evolves. All mineral coal varies much in chemical composition, and ranges between peat and carbon that is almost pure.

Brown Coal.—The external appearance and texture of brown coal vary as much as its chemical composition. Its color varies from a light brown to a deep black. Some specimens are very friable; others very hard. Its structure clearly shows it to be the remains of a vegetable world; for the identical woody fibre, the form of trunks and limbs of trees, even the minutest leaves and fruit, are exhibited with striking distinctness. Coal beds resemble an irregular pile of trees, limbs, and leaves. The powder of this coal is always brown. Sometimes brown coal is called lignite, fossil wood, or bituminous wood—terms which are not sufficiently distinctive.

Brown coal generally contains a large amount of water. Some specimens contain forty-three per cent., and scarcely any contain less than twenty per cent. Exposed to a dry atmosphere, brown coal is very apt to fall into slack, and lose a great deal of its moisture; but it never becomes entirely dry. It is thus evident that this coal constitutes a very imperfect fuel—inferior even to peat.

The amount of ashes is less in brown coal than in peat, and varies from 1.50 to 27.2 per cent., as in Irish coal. A remarkable difference sometimes exists in the quantity of ashes yielded by the same piece of coal. Brown coal is very seldom of any use in the manufacture of iron,

partly on account of its friability and its moisture, but more particularly on account of the composition of its ashes. Its ashes generally abound in sulphates, or sulphites, which impart sulphur to the iron, and make it red-short. We should, therefore, be very careful in the use of this coal in iron manufactories. We give an analysis of two different kinds of brown coal-ashes. In 100 parts of ashes there were found:—

Sulphate of lime	. . . . .	3.6
Sulphite of potash	. . . . .	1.9
Sulphite of lime	. . . . .	25.4
Sulphate of iron	. . . . .	50.0
Sand	. . . . .	19.1

Another specimen contained, in 100 parts of ashes,

Sulphate of lime	. . . . .	75.50
Magnesia	. . . . .	2.58
Alumina	. . . . .	11.57
Oxide of iron	. . . . .	5.78
Carbonate of potash	. . . . .	2.64
Sand	. . . . .	2.03

The amount of sulphur, as exhibited by these analyses, is so great that it is dangerous to use such coal in the manufacture of iron. If the quality of its ashes will permit its use in the manufacture of alum, it may be considered a very cheap and useful article.] It is highly probable that much of this coal will be found west of the Mississippi, in the new States and in the Territories. Hence these remarks are of importance to those who may have their attention turned to its use in those regions.

[The composition of the combustible part of brown coal forms the connecting link between peat and bituminous coal. The analysis of 100 parts of this coal gives us the following result:—

		Carbon.	Hydrogen.	Oxygen.
Friable brown, I.	. . .	50.78	4.62	21.38
“ “ II.	. . .	70.49	5.59	18.93
Black lignite, I.	. . .	51.70	5.25	30.37
“ “ II.	. . .	63.29	4.89	26.24

The residue exhibits the amount of ashes. Nitrogen is frequently found in this species of coal, but it seldom amounts to 1.50 per cent.

Bituminous Coal—Pit Coal.—This species of coal possesses peculiar interest, because of the immense quantity of it which exists throughout the globe, and especially in our own country. The Pittsburg coal field, consisting entirely of this coal, is superior in magnitude to any in the known world. Besides the coal field of Pittsburg, there are immense coal fields in Maryland, Virginia, Alabama, Illinois, and other western regions, which not only rival the largest in Europe, but which will afford, in all time to come, an inexhaustible store of fuel. This species of combustible deserves the special attention of the iron manufacturer. Its quality is generally good, its application simple, and its price, beyond comparison, the most reasonable of any other kind.

Bituminous coal is characterized by its dark black color, and highly vitreous lustre. Its powder is black. In some of this species, fibres of wood resembling soft charcoal may be distinctly seen. Some specimens contain more or less sulphur in the form of the yellow sulphuret of iron, visible by the naked eye. This is a mechanical admixture. If the quantity of this sulphuret is very large, the coal is unfit for the manufacture of iron. This coal is mostly stratified parallel with the direction of the vein, and breaks into square, almost cubical pieces.

Good pit coal contains very little water in admixture. Its close texture and its resinous character prevent the penetration of air or water. But if the coal is very friable, which is frequently the case with the external portion of the veins, water may exist in the crevices; but in amount so small as scarcely to injure the quality of the coal.

The ashes of bituminous coal are generally composed of silex and alumina; seldom of lime, magnesia, or any other base; and for this reason possess much interest. The amount of ashes in this coal varies from one to twenty-five per cent.; coal which contains more than five

per cent. of ashes should scarcely be used in the blast furnace. If any is used which contains a greater percentage than that, the furnace will not work well, and a great loss of iron, or the production of bad iron, is the consequence. Even in puddling furnaces a large amount of ashes is injurious.

For the sake of comparison, we give two analyses of ashes from this species of coal:—

Ashes from a species of French coal yielded of		White ashes of American coal yielded of	
Sulphate of lime . . .	80.0	Silex	85.7
Lime	3.8	Lime	2.5
Silex	14.2	Alumina	8.2
Oxide of iron	1.7	Sulphate of lime . . .	3.6

We here observe the great preponderance of the electro-negative over the electro-positive elements. How far this circumstance interferes with the manufacture of iron will be investigated under the heads of the theory of the blast furnace, and the philosophy of manufacturing wrought iron.

Chemical Composition.—The chemical composition of the combustible parts of bituminous coal ranges between that of brown coal and anthracite. An analysis of 100 parts of this coal exhibited the following result:—

Splint coal.*		Cannel coal.		Glance coal.†	
Carbon	70.9	Carbon	72.22	Carbon	90.10
Hydrogen	4.3	Hydrogen	3.93	Hydrogen	1.3
Oxygen	24.8	Oxygen	21.05	Oxygen	6.5

This coal generally contains from 1 to 1.5 per cent. of nitrogen; which, however, for our purpose, is of no consequence.

The above table shows that the quantity of hydrogen and oxygen is less than that in woody fibre, peat, and brown coal, a circumstance worthy of notice.

Practical Remarks.—Much that is highly interesting might be said concerning this article, but we are forced to condense our observations as closely as possible.

* A coarse kind of cannel coal.

† An anthracite of slightly bituminous nature.

The thickness of coal seams, as distributed in the stratified coal measures, varies from an inch to fifty feet. Veins less than two feet thick are hardly worth working. High wages would absorb nearly all the profit derived from working them; besides, such veins seldom afford as good a quality of coal as is needed for the manufacture of iron. These veins are generally slaty and sulphurous, and, except in cases of necessity, should be rejected. Veins more than two feet thick are generally of better quality, as well as more workable. In fact, coal three feet thick can be raised at very nearly the same cost as veins of greater thickness. In an economical point of view, therefore, a thick vein presents but little advantage.

Geologists have classified this coal from its external appearance, without any relation to its chemical composition. The English coal-diggers distinguish four kinds, to wit: 1, cubical coal; 2, slate or splint coal; 3, cannel coal; and 4, glance coal. Whether this classification is a correct one, we will not venture to say; for our purpose, at least, it has no specific use. The only exact basis of classification is that of chemical composition. But for the sake of usage we will adopt the classification commonly presented.

1. *Cubical Coal*—Pittsburg seam—is black, shining, compact, and tolerably hard. It comes from the mines in almost cubical masses. The general direction of the vein is that of the cleavage. This coal cakes with facility, and on that account is valuable to the blacksmith, for it forms very readily a wall and a vault around his fire.

2. *Slate, or Splint Coal*, seam next above the Pittsburg, is of a dull black color, very compact, harder than cubical coal, and mined with greater difficulty. It splits very readily, like slate, but resists cross fracture; it separates in large, square-edged masses, and burns without caking. It is somewhat heavier than cubical coal, and frequently yields a considerable bulk of white ashes. Where it does not contain too much ashes, it is an excellent fuel for the blast furnace.

3. *Cannel Coal* generally lies in seams below the Pittsburg vein. Its color is between velvet and grayish-black; it has a resinous lustre. It is as hard as splint coal, kindles like pitch, and burns with a white bright flame. This coal works very clean in the mine, and scarcely soils the fingers when rubbed. It is found in Ohio, Missouri, West Virginia, and in other parts.

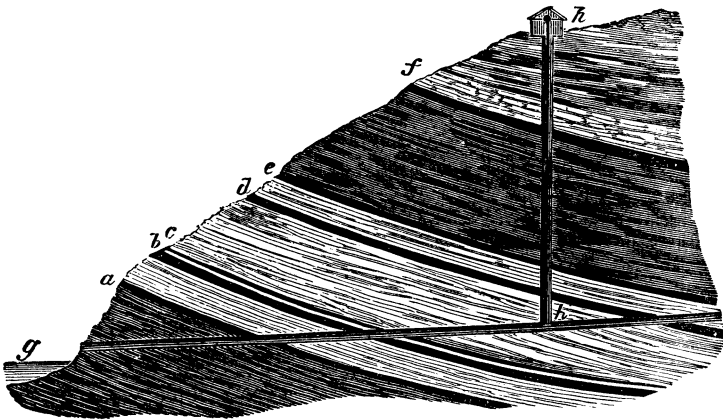
4. *Glance Coal* very closely resembles anthracite, and is of an iron black color. Occasionally, it exhibits an iridescence somewhat resembling that of tempered steel. It has a beautiful metallic lustre, does not soil, and its fragments are sharply edged. It forms coke with difficulty.

The classification just presented is unquestionably a very imperfect one, because it furnishes us with no marks by which the different classes are distinctly indicated. This is evident from the fact that the same vein not unfrequently contains all the varieties included in these classes. A correct classification would include all bituminous coal, so called from its resinous aggregation, and the amount of hydrogen it contains. This class may very easily be distinguished by its property of forming coke; for wood, peat, brown coal, and anthracite do not yield this article.

Mining of Coal.—Where coal fields are situated above the water level, and with the advantage of ascent, the working of coal is comparatively easy. The pit water flows off by itself, and there is but little trouble in ventilation. In such cases, all that is required is, to open a drift, to timber it well at the mouth, and to make such arrangements in train or plank roads as will afford a quick and easy hauling. A very cheap and useful arrangement is that, formerly, of some Pittsburg coal-diggers. A two-wheel cart, of about twelve bushels capacity, is pushed on a plank track by a man, assisted by a strong dog, which runs before the cart. We have never found much advantage in a large, high, and wide drift or level. We have paid quite as high a price for hauling by horses or mules on an iron tram-road, as that paid for the use of the above-mentioned cart. Where

a coal mine is very extensive, or where the wagons have to be pulled up an ascent, a wide track, and horses and mules, may be advantageous; but, considering the cost of a spacious drift, rails, wagons, &c., very little is gained in expensive improvements. A plank track is easily removed; it may be turned in any direction, even to the very face of the work-rooms, and will last a long time, if constructed of good white oak. We have paid twenty cents for hauling one hundred bushels from the room to the mouth of the pit, and tolerable wages were hardly made at that; while an equal amount readily pays reasonable wages, if the above-mentioned hand-cart or dog-cart is employed. If locality, or other circumstance, does not permit an opening or drift according to the inclination of the coal, it is necessary to drive a dead level in the coal to drain the mine of water; and in case this cannot be done, a dead level below the coal must be drifted until the coal is reached. This is illustrated by the following diagram: *a, b, c, d, e, f*, represent coal

Fig. 17.



Draining level.

veins, and *g*, a dead or water draining level, which, of course, can be used as a winning level. The shaft *h* may be used as a ventilator of the pit, or both ventilator and winning shaft.

Coal veins, situated above the water level of the country may be worked at but little expense, that is, require no immediate capital; but if they are situated below the water level, more attention and greater means are required. If the coal is so low that a mine cannot be drained by a level, machinery, either water-wheels or steam-engines, as well as pumps to raise the water sufficiently high to permit its flow into the nearest river, must be resorted to. In such cases vertical shafts are in common use. Such a shaft is constructed of timber, walled with stones or brick, or of iron cylinders. Its dimensions depend entirely on the amount of coal required to be hoisted. If the section of such a pit, or shaft, is round, it should never be less than ten feet in diameter; it may be enlarged to twenty feet. Such a shaft must be divided into different compartments, one of which should be always reserved for pumps and water-pipes. The following diagrams represent its various forms: *a, a* are designed for the pumps. If this shaft

Fig. 18.

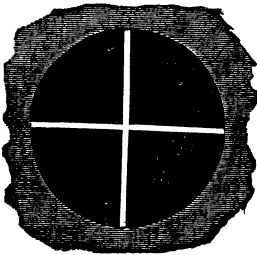


Fig. 19.

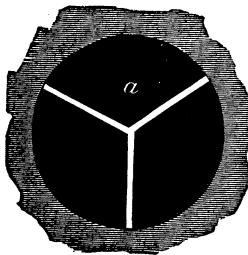
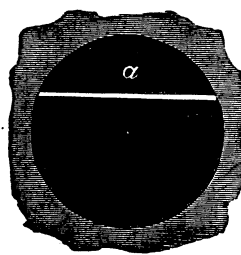


Fig. 20.



Sections of shafts.

is made of a square instead of a round form, it should not be less than eight by ten, or ten by twelve feet for a double pit. Where the coal is not too far below the surface, say fifty or one hundred feet, inclined planes may, in some instances, be preferable to vertical pits. In such a case the section may be smaller, and the same railroad cars that are used above ground may be used below ground. But whatever plan is adopted, the shaft should be sunk to the lowest point of the coal vein.

The working of coal by means of a shaft is, in fact, not more expensive than that of more highly located veins. It is attended with some disadvantages to the workmen; these are generally balanced by a good roof. But the expense of shaft ventilation, engine, and pumps falls heavily on the proprietor; this once met, the work may be prosecuted cheaply and with facility. A good circulation of fresh air is effected only at great expense, and with considerable difficulty; this circumstance needs great attention in extensive coal mines. There is no reason at the present time why iron masters should go to a great depth for coal. Coal above the water level is so abundant that any further consideration of deep coal pits would be superfluous.

The mode of working a coal vein depends on several circumstances: partly on the roof, upon the kind of coal, whether for our own use or for the market, and upon the thickness of the vein. The following are the methods practised:—

1. Working with pillars and rooms, where the pillars left bear precisely that proportion to the coal excavated which is required to support the incumbent strata or roof. These pillars are generally lost.

2. Working with post and stall. Here the pillars left are of a larger size than usual, and stronger than is requisite for supporting the superior strata. These are so constructed that they may be removed whenever the regular work is done. This method of working is best adapted for coal veins more than three or four feet thick.

3. Working with post and stall, or with comparatively small rooms. By this method, an unusually large proportion of coal is left, with a view of working backward towards the starting point, whenever the coal field is worked to the whole extent; then by taking away every pillar completely, if possible, the roof is permitted to fall in, following the miners as they retreat.

4. Taking out all the coal, and leaving no pillars at all. By this plan, the roof falls in as the diggers retire.

The first two methods are practised for the thicker

coal seams. Where the veins are thicker than three feet, the two latter methods are dangerous and expensive. Where the coal, roof, and pavement are of equal hardness, the first and second methods will answer; but where the pavement is soft, the pillars should be uncommonly strong to prevent the sinking of the coal. They should be equally strong where the coal is soft, for otherwise they would be crushed, and the coal lost. The same principle may be extended to a roof that is soft and brittle.

Bearing all these circumstances in mind, it may be stated, generally, that, where the coal, roof, and pavement are strong, all the above methods may answer; but where they are soft, strong pillars and rooms of moderate size are required: in this way, when the miners retreat to the starting-point, the greater part of the coal may be got out.

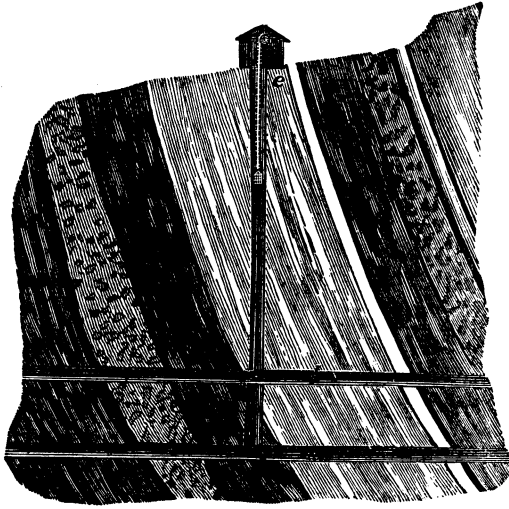
The proportion of coal taken out to that left in the pillars, when it is our intention to remove all the coal at the first working, varies from four-fifths to two-thirds. A loss even of that amount throughout the whole area of the coal field, ought to be prevented. If no accidents happen, this can be done by adopting the third plan.

When a coal field is opened, and a systematical method of working is resolved upon, we should divide the coal field into square spaces, where pillars, rooms, and roads are properly laid out. In accordance with this plan must the air pits be situated, and a system of ventilation arranged which will secure both the safety of the working men, and the progress of the operation. Where the coal is soft and friable, particularly where it is slaty and sulphurous, perfect ventilation is indispensable. Hard, clean coal is not so dangerous, and requires, therefore, less care. Coal pits ought to be opened in summer, and continued during winter; an air shaft should be driven during the winter, that a progressive work for the warm season may be secured.

If the coal stands edgewise, or nearly perpendicular, the thickest stratum of rock is the best place for driving a shaft. The pit should be strongly timbered or walled,

to prevent its being crushed. Whenever the shaft has its proper depth, galleries must be driven across all the coal strata, as shown in Fig. 21. These galleries can be

Fig. 21.



Opening of galleries.

multiplied for the greater convenience of the winning. All the coal is taken out at the working shaft *c*.

For lifting coal in a shaft, chains or ropes are used; the former are dangerous, and often unexpectedly break. Hemp ropes are more safe, but they are expensive. We doubt whether wire ropes will, in all cases, answer the purpose; for, besides the friction of coal, sand, and mud, the pit water is very destructive. For these reasons, hemp or manilla ropes are, in some mines, probably the cheapest as well as the best.

If coal veins are not horizontal or vertical, the best plan is to follow with the shaft the dipping of the coal, and hoist on an inclined plane or "slope." All the other arrangements, as pumps, &c., should be constructed in accordance with this principle.

The price of digging coal varies much. In Frostburg, Maryland, a ton of coal is dug in the thick or

twelve feet vein at twenty-five cents; in thinner veins, in the same region, at from fifty to seventy-five cents; sometimes as high even as a dollar is paid for a ton of twenty-three bushels. In the Pittsburg vein, the price varied, formerly, from one cent and a half to two cents per bushel, and a vein of the same thickness, twelve feet, could be dug in the counties of Armstrong and Westmoreland, Indiana, at one cent a bushel. Great difference in the price is occasioned by the difference in the quality of coal—whether it is designed for our own, or for market use. If the coal is to be screened, and the slack removed, workmen demand, and of course deserve, higher wages, than when mixed coal and slack are received. Wages also depend, in a great measure, on the quality, softness or hardness of coal, upon the thickness of the vein, and upon the roof and pavement. Workmen may make good wages at one cent a bushel in one place, and poor wages at five cents a bushel in another place. As a general rule, a six feet vein, with a strong, hard roof and pavement, and a strong coal, with soft undermining, is, of all others, the most favorable. The hauling of coal from the work rooms to the mouth of the pits is a matter of great importance, for imperfect roads, wagons, water, &c., bear heavily upon the transportation of coal. In one case ten cents a ton may be ample remuneration; while, in another case, respectable wages cannot be made at thirty cents a ton. Sometimes one set of hands contract both for hauling and digging. This is a good arrangement; but, where the coal mines are extensive, it is not practicable.

The most prevailing method of valuing coal, as well in trade as in digging, is by measurement. Any intelligent man must be convinced that this is a very imperfect method of valuation. The value of coal can be deduced from its specific gravity alone; and therefore depends upon its absolute weight. A proper deduction must of course be made for the ashes it contains. The specific gravity of coal varies, sometimes in the same vein, from 1.2 to 1.9—a difference of thirty per cent. That is to say, a given quantity of coal may furnish just

thirty per cent. more combustible matter than another equal quantity in the same vein. Sooner or later, measurement by *weight* will be generally introduced in the coal trade. This will benefit the producer no less than the consumer. Whether a ton is assumed to be 2000 pounds, or 2240 pounds; whether this or that standard of measurement by weight be adopted, it is certain that uniformity of estimation would soon settle the real value of coal. In our case, this method would be even of more consequence than to the public and the trade generally. In England, coal is sold by the chaldron; in Germany and France, by weight; in the United States, by almost every variety of weight and measure.

Anthracite.

The following incidents in the history of the earliest attempts to introduce anthracite into the blast furnace we received from David Thomas, Esq., of Catasauqua, Pa., and they will be interesting in this place. Mr. Thomas had tried charges of anthracite one-half, one-twelfth, etc., to one of coke, with no good result, at Yniscedwyn, Wales (Ynis, Island, pronounced Inniskedwin). In 1817 there was in that region but one furnace. It was in the spring of 1826 that the experiment with anthracite was tried. The furnace was built in an anthracite region, but other coal was brought by water from fourteen miles distance. In September, 1836, he received a pamphlet from Neilson. Mr. Thomas was in the habit of supping with Mr. Crane, the proprietor of the works. One night while talking "coal and iron," he took up the bellows and blew upon the anthracite in the grate, near to which they were both sitting. "Now," said Mr. Thomas, "if we had Neilson's hot blast, what would prevent the use of anthracite, which is found all about us?" The next morning Mr. Crane asked Mr. Thomas if he had thought of the suggestion of the previous night. Mr. T.'s reply was that he had "scarcely slept for the thinking." Mr. Crane asserted that he also had been sleepless under the excitement of the same

thoughts. It was then suggested that Mr. Thomas should go up to Glasgow immediately and see Neilson. Mr. Thomas went, and at the Clyde works obtained the castings, had them shipped, and after some little delay, the hot blast was in operation and succeeded at the first to perfection. The bosh of this furnace was eleven feet, height thirty-five feet, pressure about four pounds.

This was the first successful application of anthracite to smelting iron in the world. Mr. Crane was not a practical iron manufacturer, but brought up in the hardware iron business. Mr. David Thomas, now living in a hale old age at Catasauqua, Pa., was the man to whom all the credit is to be given.

The coal of Swansea is bituminous low down, and semi-bituminous near the surface; that at St. David's is anthracite, and the anthracite of Wales is so much like our Pennsylvania anthracite that no one could easily perceive any difference. The three upper veins of Swansea are semi-bituminous.

When the successful application of anthracite to the metallurgy of iron in Wales was apparent, the owners of some anthracite mines largely advertised the Welsh success in the London mining journals. The success thus announced attracted the attention of gentlemen interested, in this country, and Elisha Hazzard went to Wales and invited Mr. Thomas to this country. He agreed to go, and signed the agreement December 31st, 1838, at 12 o'clock midnight. Burd Patterson built the furnace (the Pioneer) at Pottsville, Pa., where the attempt was first made, and the furnace was finished Oct. 1839, for William Lyman, of Boston, but he gave up business a few months afterwards, and the attempt to use anthracite was abandoned at that time. Mr. Thomas first came to Catasauqua and put up Furnace No. 1 (Crane iron works), at which furnace that first successful effort at making anthracite iron was attempted, which has been continued ever since. For some time it was considered hopeless by outsiders, and one iron master promised Mr. Thomas to "eat all the iron he could make by use of anthracite." Some months after Mr. T.'s suc-

cess, he was breakfasting in Easton, Pa., at (formerly) White's hotel, when, the gentleman being present who made the offer, Mr. Thomas informed him that he now had some hundreds of tons ready for his dinner!

To-day, perhaps, the most magnificent blast engines for metallurgical works in the United States are to be found at these very Crane iron works, upon the Lehigh, four miles above Allentown, Pa. The following are the dimensions of No. 7 engine:—

Diameter of steam cylinder	66 inches
Diameter of blowing cylinder	108 “
Length of stroke	10 feet
Diameter of fly-wheel	30 “
Weight of walking beam	68,000 pounds
Delivery of cubic feet per minute, at 15 strokes per minute . . . . .	.15,000.

This splendid engine is one of the results of the enterprise of the year just past, 1868, inaugurated by those truly “iron” men and masters at both the Crane and the Thomas works on the Lehigh, for the engines at the Thomas works are equally splendid, varying, we understand, by only the imaginary difference of thirty-five pounds in the beam. This is the progress of twenty-nine years.

Anthracite is too compact to absorb much water, or to contain it in admixture. The amount of ashes is often very considerable, varying from one to thirty per cent. Their chemical composition is principally silex, with but little alumina, and sometimes oxide of iron.

Chemical Composition.—The composition of anthracite resembles very closely that of charcoal and coke. Hydrogen and oxygen, gradually diminishing, amount, in the most perfect specimens, to scarcely anything. We present an analysis of anthracite:—

Pennsylvania.		South Wales.		Massachusetts (Worcester).	
Carbon	94.89	Carbon	94.05	Carbon	28.35
Hydrogen	2.55	Hydrogen	3.38	Hydrogen	0.92
Oxygen	2.56	Oxygen	2.57	Oxygen	2.15
				Ashes	68.65

Practical Remarks.—Anthracite which contains more

than five per cent. of ashes is a great trouble in the blast furnace, and but little better in the puddling and reheating furnaces. But good anthracite is undoubtedly the most perfect of all fuels for the manufacture of iron. Its application is simple; its hardness prevents it from falling into slack; and the small amount of hydrogen it contains makes it advantageous for the blast furnace operation. By proper application, anthracite will supersede, in economy, bituminous coal. The mining operations of anthracite are more simple than those of bituminous coal. Less danger is to be apprehended from the effect of bad air or coal-damp; therefore less expenditure for ventilation. It is so hard that the last remains of coal can be removed from the mine, and hence less expenditure for the coal.

General Remarks on Fuel.—Wood is yet so abundant in some parts of the United States, that charcoal furnaces and forges may be carried on for a great length of time, without apparently diminishing its quantity; still, so rapidly are civilization and wealth progressing, so rapidly is the consumption of iron augmenting, that our attention cannot be otherwise than forcibly turned to mineral fuel as a substitute for wood in the manufacture of iron. Peat, or turf, is not sufficiently distributed, nor so fully introduced into the market as to deserve much attention. There are peat bogs in the States of New York, Michigan, Rhode Island, New Hampshire, Maine, Massachusetts, and in other States; but its application in our country is limited and it will not be used to any great extent for iron manufactures for years to come. In France, Germany, Bohemia, and Russia, peat is used for the manufacture of iron; but here, independent of any other cause, the cost of peat would prevent its application for this purpose. In countries where no mineral coal exists, its application may be advantageous. The reasons we have given against the use of peat, apply equally well against the use of brown coal. Some kinds of lignite constitute a good fuel in the puddling furnace, as well as in reheating and sheet ovens; but their application to the blast furnace must be very limited.

Lignites found in the United States are very properly used only for the manufacture of alum and copperas.

Of all the coal deposits, those of anthracite and bituminous character deserve our closest attention. Their utility in the manufacture of iron, and their extraordinary magnitude throughout the United States, give to the iron business of this country prospects the most flattering of those of any nation, or of any time. England was once supposed to include the great coal deposits of the world; but these shrink into insignificance when compared with the gigantic deposits of the United States. The amount of coal distributed throughout the world is as follows:—

United States of America . . .	130,000 square miles
Anthracite of Pennsylvania . . .	470 " "
British America . . .	18,000 " "
Great Britain and Ireland . . .	12,000 " "
Spain	4,000 " "
France	2,000 " "
Belgium	518 " "

How great the prospect, how extensive and durable the basis of comfort, prosperity, and happiness, to the citizens of the United States, this immense wealth of mineral fuel discloses! The distribution of coal throughout the different States of the Union is as follows:—

Alabama	3,400 square miles
Georgia	150 " "
Tennessee	4,300 " "
Kentucky	13,500 " "
Virginia	21,195 " "
Maryland	550 " "
Ohio	11,900 " "
Indiana	7,700 " "
Illinois	44,000 (?) " "
Pennsylvania	20,000 " "
Michigan	5,000 " "
Missouri	6,000 " "

By this table, we find that England, Ireland, Scotland, and Wales united, contain about as much coal as the State of Ohio. We have omitted, in the above esti-

mate, the smaller coal tracts in different States, as not worth mentioning.

United States Coal Measurement.—

Ordinary estimate of bitu-

minous coal: 28 bushels=1 ton at 2240 lbs.

At some places, 30 “ “ “

We also find it stated at . 26½ “ “ “

At Richmond, Virginia, coal pits, a bushel=5 pecks=90 lbs.

The same coal on board a vessel “ =4 “ =72 “

In the south, bituminous coal is sold by the barrel, weighing $172\frac{1}{2}$ =13 barrels=1 ton.

In New York, as well as Boston, and elsewhere in the East, a ton of coal=2000 lbs.

On the State Canal and Tidewater Canal, Pa., toll is levied at 1000 lbs.

In Pennsylvania, Ohio, and several other States, a bushel=80 lbs. of coal.

Nova Scotia coal is sold by the chaldron=3360 lbs., or 42 bushels.

In Boston, the retail chaldron is but 2500 or 2700 lbs.

Prices of coal at the pits:—

In France	\$1 50 to \$3 50 per ton
“ Germany	1 75 “ 2 50 “ “
“ England	1 50 “ 2 50 “ “
“ Pennsylvania (anthracite) .	2 00 “ 2 25 “ “
“ Pittsburg (bituminous) .	50 “ 1 00 “ “]

Only a few years ago, the sources of heat for all metallurgical purposes were confined to the best qualities of charcoal, and to anthracite and bituminous coals. Antecedently, they were still further limited to bituminous coal and to charcoal, the bituminous being used either as “raw” or coked, the anthracite being characterized as coal that will not “coke,” a term which expressed that condition in which the bituminous or hydro-carboniferous substances were absent, having been driven off by heat. Late inventions, however, especially that of the Siemen’s furnace, enable us, in the rolling mill, not only to use inferior kinds of *bituminous* coal, but also *peats* of various qualities as well as *lignites*, and perhaps, may

enable us, hereafter, to use the lower grade of peat, known in other countries as *turf*. In many places iron companies are turning their attention to the working or "winning" of their own bituminous and anthracite coals. Fuel, therefore, of little importance to one company, may be of great importance to others. It is for this reason that we treat not only of those fuels which are used at present, but also of those which will, with all probability, in a few years, be used where now they are not used. In Styria both lignite and peat are used with a great degree of success in puddling iron, and there is no reason why the same may not be done in this country. The comparative effects in the furnace are noticed, hereafter, under "Practical Remarks upon Puddling." Peat is now being prepared, by processes adopted in Massachusetts, and in New York, near Lake George, and elsewhere, so that it is dry and burns well, but as was intimated, great care must be used to avoid this fuel when rendered either uneconomical, or injurious to iron, the former by water, the latter by chemical ingredients.

But the points of great practical difficulty are found in the varying amounts of weights and of quality in mineral fuel, and particularly in anthracite. These peculiarities have probably caused more loss in iron manufacture than many are aware of. A review of the following tables will show the variations of weight, and hence density of coals from different regions.*

Anthracite and Anthracitous Coal.

EUROPE.	Specific gravity.	Weight per cubic yard in pounds.
South Wales :—Swansea	1.263	2,131
Cyfarthfa	1.337	2,256
Ynisedwin	1.354	2,284
Average	1.445	2,278
Ireland, mean	1.445	2,376
France :—Allier	1.380	2,207
Tantal	1.390	2,283
Brussac	1.430	2,413
Belgium :—Mons	1.307	2,105
Westphalia	1.305	2,278
Prussian Saxony	1.466	2,474
Saxony	1.300	2,193
Average of Europe		2,281

* Modified from Taylor's Coal Statistics, by Dr. Ure.

AMERICA.	Specific gravity.	Weight per cubic yard in pounds.
Pennsylvania:—Lyken's Valley . . .	1.327	2,240
Lebanon Co. Gray Vein . . .	1.379	2,327
Schuylkill Co. Lorberrry Creek . . .	1.472	2,484
Pottsville Sharp Mountain . . .	1.412	2,382
“ Peach “ . . .	1.446	2,440
“ Salem Vein . . .	1.574	2,649
Tamaqua Worth Vein . . .	1.600	2,700
Mauch Chunk . . .	1.550	2,615
Nesquehoning . . .	1.558	2,646
Wilkesbarre, best . . .	1.472	2,884
West Mahoney . . .	1.371	2,313
Beaver Meadow . . .	1.600	2,700
Girardville . . .	1.600	2,700
Hazleton . . .	1.550	2,615
Broad Mountain . . .	1.700	2,869
Lackawanna . . .	1.609	2,715
Massachusetts:—Mansfield . . .	1.710	2,882
Rhode Island:—Portsmouth . . .	1.810	3,054
Average in the United States		2,601

From an examination of the above tables, it is plain that the anthracites of Europe and of the United States vary in weight per cubic yard in proportion of 2281 lbs. to 2601, and by calculating the average specific gravity, it will be found that that of European anthracite is 1.366 against 1.541, which is very nearly corroborated by the proportions in which the weights per cubic yard are taken as elements, as the following proportion will show, viz.:— $2.281 : 1.366 :: 2601 : 1.557$, wherein the specific gravity, 1.557, varies very little from 1.541 for the practical purpose to which we refer.

Thus far it is plain that the anthracites of Europe differ from those of the United States, and, indeed, so much so, that the latter are 12.8 per cent. heavier than the former. But our practical object leads us to pass from this part of the subject to another, although we say, in passing, that that fact alone is sufficient to show that the furnace treatment in the two parts of the world may differ materially for the same reasons adduced hereafter.

Whilst this difference exists in regions so far apart, we find, from the same tables, that even in the United States the difference of densities is equally great, for in this case the specific gravity and density are, practically, the same. It is well known among those acquainted with the anthracite basins, not of Pennsylvania,

Massachusetts, and Rhode Island, the latter two scarcely worth mentioning, but of Pennsylvania alone, that even on a line of only ten miles the eastern coals are denser than those of the western slopes of the same continuation. Now, by an examination of the anthracites of any one section by itself, it will be seen, that the density varies considerably. Notice the progressive variation in the same district of the southern, or Schuylkill field, Lyken's Valley, Pottsville, and Tamaqua being the representations of the western, middle, and eastern parts of the same line and basin east and west. The variations are as 1.327, 1.412, 1.600, that is, the coal at Pottsville is 6.4 per cent. denser than that at Lyken's Valley, while that at Tamaqua is over .13 per cent. denser than that at Pottsville, and no less than *twenty per cent.* denser than that at the west end. But still more important is the fact that in the same immediate region these coals vary as seen by this table. Notice the variation in the Pottsville coals alone.

Now the practical bearing of this variation upon metallurgical matters is this, that an increase of density of all fuel, as in this case of coal, requires very material variations in the mode of furnace management, a difference in the pressure of blast, an increase or decrease in the temperature of the hot blast, and a corresponding variation in the nature and proportions of the charges of ore and flux, or a variation in the quality or quantity of the iron made will certainly follow.

But further, we would direct attention to the following table:—

*View of the Composition of some of the Anthracite Coals of
Pennsylvania.*

Locality of coal.	Sp. Gr.	Vol. matter.	Carbon.	Ashes.
1. Summit Co.'s lands, head of Beaver Creek	1.560	6.42	97.30	1.28
2. do. do. 2d bed . . .	1.594	4.31	91.69	4.00
3. do. do. 3d bed . . .	1.613	7.51	87.48	5.01
4. do. do. 4th bed . . .	1.630	9.60	85.34	5.06
5. Stevenson's Bluff, west of Beaver Meadow . . .	1.613	9.23	86.06	3.71
6. Buck Mountain . . .	1.559	5.90	91.02	3.08
7. Sugar Loaf Company, 1st specimen . . .	1.591	6.98	88.19	4.83
8. " " " 2d bed . . .	1.574	5.36	85.91	8.73
9. " " " same bed but further down the slope . . .	1.550	6.87	90.71	2.42
10. Lyken's Valley, 1st sample . . .	1.391	7.60	87.95	4.45
11. " " 2d " . . .	1.404	5.95	89.30	4.75
12. " " 3d " . . .	1.416	10.00	85.70	4.30
13. " " 4th " . . .	1.374	4.60	88.70	6.70
14. " " 5th " . . .	1.376	8.35	87.75	3.90
15. " " 6th " . . .	1.395	8.30	88.65	3.05
16. " " 7th " . . .	1.382	8.65	87.20	4.15
17. " " 8th " . . .	1.398	11.85	84.00	4.15
18. " " 9th " . . .	1.378	7.30	87.00	5.70
19. Mauch Chunk, Summit Mines . . .	1.590	7.90	87.10	5.00
20. Room Run Mines . . .	1.604	6.15	87.20	6.65
21. Pottsville . . .	1.569	6.71	86.54	6.75

In regard to this table, which is the result of Prof. Walter R. Johnson's analyses, that gentleman says, that the first nine give a fair average of the coal at the eastern extremity of the middle coal field, and show that the volatile matter is 6.91, the fixed carbon 88.744, and the ashes 4.346 per cent. The second nine give the character of the northwestern termination of the southern anthracite field. The mean per cent. of volatile matter is here 8.066, of carbon 87.36, and of ashes 4.574. The latter ingredients being similar to those in the coal used by Mr. Crane in his iron works in South Wales. Now, while we notice the increase of volatile matter and the decrease of specific gravity as we go westward, we would turn attention to the fact that while, in the same mine, the density is increased, the amount of carbon is frequently not increased, as in the case of the first and third of the mines in the list. And we would turn at-

tention particularly to the further illustration of this fact in the instance of the 18th locality and 9th sample of Lyken's Valley coal compared with the Mauch Chunk summit mines coal, wherein the latter is more than 15 per cent. heavier, and yet has only the tenth of one per cent. more carbon to show for all this increased specific gravity.

These two facts, therefore, are apparent, that in the same region, there is often (1) a great variation in the density of coal, and (2) that there is frequently within the same limits a very great variation in the heating value of the coal. In the latter case, for instance, the iron-master has received a coal from the same region which contains, for the same weight, ten per cent. less heating power, and which, having ten per cent. less carbon, will of course give out less CO gas, decreasing the heating power of the hot blast, and, as, in a large number of our furnaces, the coal is the constant quantity, bringing about soon an entire change in the character of the iron produced, while to the eye of the iron-master there is no exhibition of any change in coal, ore, or limestone. We have no doubt that vast sums have been lost and much trouble has been occasioned by the simple fact that the coal has become altered in density, amount of carbon, or of ashes, although from the same region. We think, therefore, that in addition to the care bestowed upon limestones and ores, some more care than has previously been bestowed shall have yet to be paid to the nature, and heating value, of the coal used in the furnace when those unaccountable perplexities happen at some furnace and which are only altered after long seasons of vexation and loss have transpired.

The above facts have presented themselves to us especially as applied to the Schuylkill coals, for through the kindness and skill of Stephen Harris, Esq., of Pottsville, Pa., whose knowledge of that and adjoining mining regions has been extensive, and as an Engineer, very accurate, we have obtained a collection from eighty-four collieries and branches, covering a very large variety of places, all of the specimens being of merchantable

coal, and the remarks we have made are sustained by thorough and careful examination of this region alone.

In addition to what we have said, it is of importance to call attention to a condition of coal which may easily be recognized by the eye. It is that in which small pearly white flakes are seen in fine fissures in the coal. An analysis, made at our request, by E. S. Moffat, proves them to be silicate of alumina in its most infusible condition, somewhat altered in various coals (Al_2O_3 32.31, Fe_2O_3 2.45, SiO_2 54.46, CaO 7.58, S 3.47 = 100.27). The presence of this impurity, because of its singular mechanical disposition, causing such minute divisions, or walls, in the substance of the coal, reduces its heating power in some cases nearly, if not quite, ten per cent. Some ten tons of this coal, last summer (1868), were tried at the rolling mill of Stewart & Co., Easton, Pa., because of the persistent recommendation of a coal agent, notwithstanding attention was called to the peculiarity. We were informed that, before a ton was used, the furnace was in such a condition that the coal had to be thrown out and new coal introduced. We mention this establishment because of the nature of the iron used and made there, since great care must be exercised in the heating, and any variation in quality of coal is immediately detected.

From the above facts it is plain, that, in regard to anthracite, judgment must be exercised as to the quality of the coal used, or else serious disturbances may occur when every other condition is in good working order.

Charring of Wood.

The most ancient way of making charcoal is, simply, to dig a hole in some dry place; to fill it with wood, and to burn a part of the wood until sufficient heat is produced to char it thoroughly; the wood is then covered with sod, or sand, or coal dust, to keep the air out; the charcoal will remain in the pit. The proper time of throwing on the covering is a matter of practical importance. This mode of charring is very imperfect, and, at present, is practised only among some uncultivated

nations; it makes bad, light fuel, and furnishes it only in small quantity.

Charring in Heaps, Kilns.—To build a kiln or heap, a dry, sandy, and, when possible, level spot, in the woods, is selected, protected from wind and gales, and as close to the cord wood as possible; the earth is to be leveled, dug, and tilled, to remove stones and stumps, and sufficiently large to permit the building of a heap of thirty feet in diameter. A circular space of from forty to fifty feet in diameter will thus be required. Great care should be taken that no spring, or water of any kind, is in the neighborhood of the level, and that sudden rain shall not overflow it. When the ground is leveled, and pounded as solidly as possible, the hauling of cord-wood should be commenced; this wood must be piled vertically around the circumference of the hearth or level, as represented in Fig. 22. The opening *a*, sufficiently large for a sled to enter, is left on the most convenient part of the ground, accessible by horses or oxen.

Fig. 22.



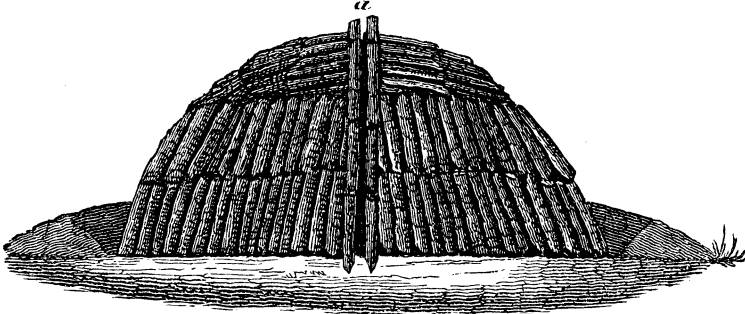
Hauling the wood to the hearth.

After all the wood is put around the hearth, the heaviest billets always to be placed inside, the collier puts either one stick, or, what is better, three stout sticks of about ten feet in length, right in the centre of the hearth, fixes them firmly in the ground, and then fastens or binds them with withes, so as to form a chimney or draft-hole in the centre of the hearth, as seen in Fig. 23.

The collier then begins to set the kiln, or pit, as it is sometimes called, by ranging the heaviest billets around the centre, at first vertically, and then gradually in a slanting position by turning the butt, or thickest end of the wood, downwards. The wood should be put as closely

together as possible, that it may be brought into the narrowest space. After it is all set, the pile (which may

Fig. 23.



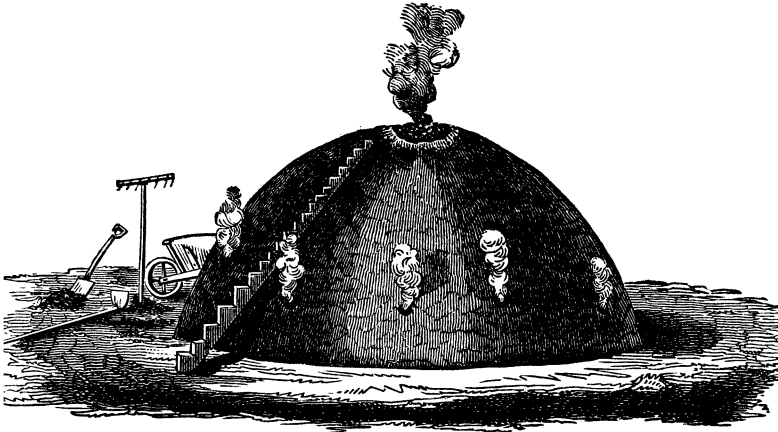
Setting the wood for charring.

amount at the first burning to twenty or twenty-two cords, and may be afterwards increased to forty, even fifty cords, according to the skill of the collier) is covered with small limbs, cut short, and with chips, &c., to fill the crevices; in fact, the pile must be made as smooth and tight as possible. The whole kiln must then be covered with leaves, about two inches thick. Some colliers are in the habit of firing the kiln as soon as the leaves are thrown on; but this practice is a dangerous one, for, should a gale happen to blow, or should it become windy before the workmen are able to cover the leaves with dust, a quantity of wood and coal is lost. The best way to proceed, is to cover the leaves with a thin layer of dust before fire is put to the kiln. The first layer of dust should be pure earth, and somewhat short, sandy, and by no means tough or clayish, for, in the latter case, it will shrink, bake, and crack. Besides, it is almost impossible to keep it tight. Where no other dust than this can be found, it is necessary to take sod, which, of course, is somewhat expensive. The first dust is always imperfect, but gets better with the progress of the work; for, after the first burning and drawing of coal, it is properly made by mixing the green dust with charcoal dust. This mixture forms a light, open

cover, admitting, frequently, a thickness of eight inches, and is, of course, the most secure and profitable. Where coke dust can be had at a reasonable price, it is the most available of all dusts. After the whole kiln, with the exception of a few feet on the top, is covered by a slight coating, the fire may be put in either by means of chips, brands, or good charcoal. It should be kindled at the bottom of the centre, at *a*, Fig. 23, and must be watched until it has fairly started; the kiln may then be left alone for at least twelve hours, provided the weather is not so stormy as to blow the cover off. Within twelve or eighteen hours, the kiln will be sufficiently heated to permit the application of more dust, and the closing of the top. Pine and dry wood will permit more time; but young wood, saplings, hickory, and maple, require closing very soon, or the kiln will get too hot, and a great deal of coal will thus be wasted. Three days, or, still better, four days after the fire is started, the cover gradually sinks, and this is the time that the hands should watch closely; for, should the heat not have been regularly distributed inside the kiln, the setting or sinking will be irregular, and the cover be very apt to leave openings, where the atmosphere, penetrating, would do great damage, in case such breaks are not directly closed. If the work has been well conducted, the cover sinks gradually and regularly, and the dust can be gradually increased, as the smoke ceases. After the smoke altogether ceases, the whole kiln may be closely covered, and left for cooling. Four or five days are sufficient to cool the kiln. As it is cooling, the drawing of coal commences. This is performed by raking the dust off from the coal at the foot of the kiln. We should be cautious not to open too much at once, for fresh coal, even when black and cold, is very apt to rekindle, and thus occasion a loss of coal and time. If the charcoal is sufficiently cold, and does not kindle, the drawing may be continued all around the kiln, but not to a greater extent than is needed to fill a wagon load; the kiln is then to be carefully covered, and left until the next wagon is ready to take a load. Sometimes it will hap-

pen that the top sinks, or that the fire is not properly kindled. In this case, the workmen must get on the very top of the kiln. That this may be done conveniently, a rough stairs or ladder is made of a round stick six or eight inches thick, as shown in Fig. 24. In case the cover is too heavy, or in case the fire draws to one

Fig. 24.



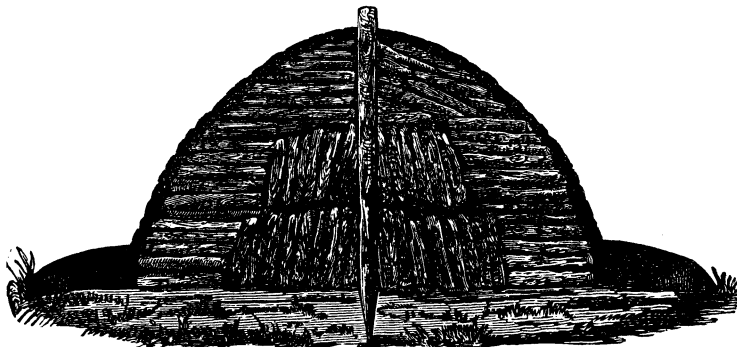
Making charcoal in heaps.

side—a circumstance which, in stormy weather, frequently happens—the hot places should receive more covering; and in the cold parts, holes should be opened by removing the dust. If the kiln is too cold at the base, holes should be made all around, that the fire may be drawn towards the bottom.

The foregoing description of charring applies to the standing kiln. It is a mode of working very much in use, and, by care and attention, furnishes good results. There is, however, one objection to it; that is, if the wood is very cylindrical, or if one end is as thick as the other, many spaces will be left which cannot be filled. These are injurious to the final result; for the circumference of the kiln will require to be sloped to make the dust stick; and to make that slope, the wood must be drawn outward at the base. To avoid such spaces be-

tween the billets, another method is frequently adopted : that is, setting the wood around the centre post vertically, and the last four feet at the circumference horizontally, as represented in Fig. 25; but the advantages

Fig. 25.



Section of a charcoal work—piling the wood.

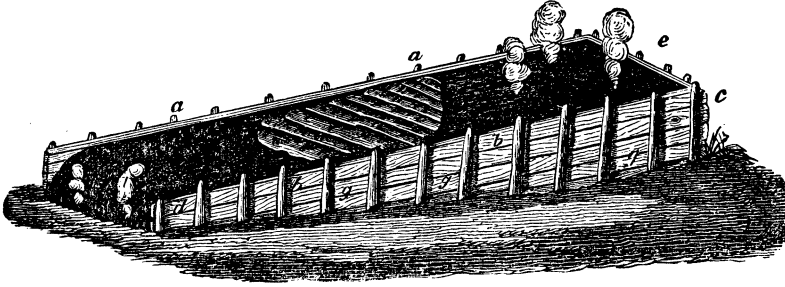
afforded by this method are not great; and it is of but little consequence which method is pursued. Care and attention on the part of the workmen are the guarantee of success. The time required to finish a burning differs, and depends on the seasons, weather, wood, dust, capacity of the workmen, and other circumstances. Winter is always a bad season for charring.

Stormy, rough winds are equally unfavorable; green wood furnishes a poor yield, and bad coal; green or heavy dust is disadvantageous; light dust is equally so. Colliers who do not understand their business, or who are not industrious and attentive, never make good coal, nor produce a good yield. If the work is unreasonably hurried, unavoidable losses are the consequence.

Charring in Mounds.—One of the most ancient modes of charring wood is by mounds. This method is practised to a great extent in the pine forests of Austria; and for pine, or well-seasoned hard wood, deserves our notice. A mound is built in the following manner: Fig. 26. A row of posts, *a*, is firmly fastened into the ground. The ground should be previously levelled or sloped. A

second row *b*, parallel with the first, and well secured, must then be similarly placed; the distance between the

Fig. 26.



Wood-charring mound.

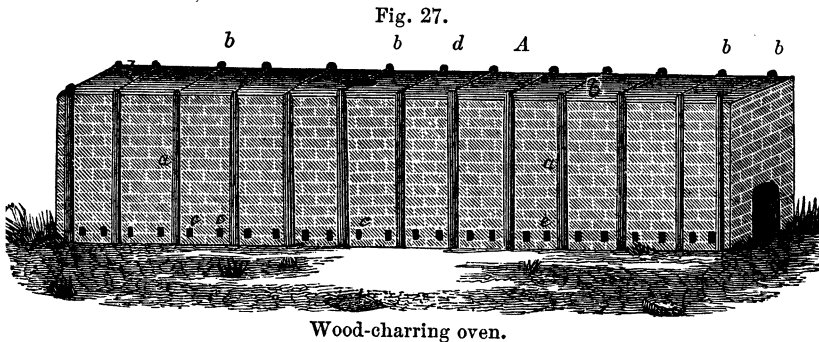
two rows is, by four feet long cord wood, eight feet eight inches. The length of such a row will depend upon the dimensions of the mound, say from forty to fifty feet, and the posts ought to be no more than four feet distant from each other; the post *c* will be six feet, and *d* only three feet above ground. Three head posts, *e*, are then put in, and the whole inside of the frame is lined with boards, lath, slabs, or even with split cord-wood. This lining is to be fastened to the posts by wooden pins. After the frame is finished, the lining fastened, and the floor pounded solidly down, the setting is commenced by throwing the wood crosswise on the floor; and, beginning at *e*, the wood is gradually piled to within three inches of the top of the lining. By packing the wood closely, a mound fifty feet in length, six feet in height at the head, and three at the foot, and eight feet eight inches wide, ought to take from twelve to fourteen cords of wood. The wood, if not too heavy, that is, if not more than twelve or fifteen inches in diameter, may be round; and if straight, eight feet in length. In that case, it packs more closely than split wood. By laying the wood crosswise throughout the length of the mound, the advantage of fast work is secured, for the coal can then be drawn gradually as the fire retires. After the wood is all in, and the top leveled with limbs or chips,

a dust, sod, or sand cover is thrown over the whole; the sides, where a space all around is to be left, are equally filled between the lining and the wood with dust, which must be firmly pounded in, to prevent the lining from catching fire. When the whole mound is covered, fire is kindled at the lower end *f*. In the mean time, some dust is removed at the top, near *c*. After the lapse of a few hours, the fire will be sufficiently advanced to permit the egress of smoke at *e*; and the dust at *f* may be thrown on again. To secure a supply of fresh air, one of the draft-holes *g, g*, on each side, may be opened. By this method, the charring proceeds rapidly, and requires watching. When the fire has advanced about ten feet, which will require a period of twenty-four hours, coal may be drawn at *f*, and continually drawn until close to the fire. This latter advantage is mainly due to the sloping of the wood-pile; and it is still greater if the pile is put on a gently sloping hill-side.

This process of making charcoal is a very ancient one. It was employed by the Romans to manufacture charcoal for their forges; and at the present day, in the very country where the ancient Romans carried on their iron establishments, this mode of charring is preferred to all others. The process now carried on in southern Austria differs not in the least from that in use at the time of Pliny. It is one of those inventions which a comprehensive genius finished, and left to posterity nothing but the task of explaining; it is so simple, practical, and complete, that no improvement is possible. How it happens that we, at the present day, in more cultivated countries, reflect so little upon this most simple and perfect mode of charring wood, is more than we are able to explain. We have both observed and practised it, and have found it to answer all the claims of the iron master. It delivers a strong coal, and yields well. It combines the advantages of the pit, the kiln, and the char-oven.

Charring in Ovens.—The inducements to invent ovens for charring wood, coal, lignite, and peat, were, partly a desire of gaining the gaseous educts of the charring process, and partly a desire of security against wind and

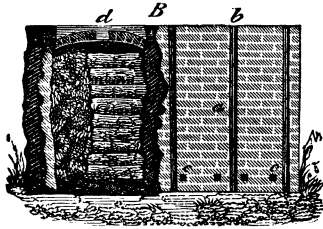
storms. The first object is only imperfectly realized; because, if the fuel for distillation is derived from the material to be charred, the combinations of hydrogen and carbon are mostly destroyed, while nothing but tar and heavy carbonized compounds are the results of the distillation. Even this is to be gained only by impairing the quality of the charcoal. The latter object is available; a well-built oven affords perfect security against wind and storm; and where the transport of wood to a general charring-place is not too high, great advantages may be derived from it. With good bricklayers, all that is required to build a good oven is close joints and good sound brick. The form of these ovens has been varied to suit almost every notion; still, it is generally agreed that ovens of less capacity than fifty, and of greater capacity than sixty cords, are less advantageous than those constructed within these limits. A further distinction is made between ovens for making black, and those for making brown, charcoal. The first are heated with their own, the latter by additional, fuel. We shall notice simply the latest improved oven of each kind. Fig. 27 represents a char-oven for wood formerly



in use near Baltimore. *A* is a side elevation, showing the binders *a, a, a*, made of cast iron; these stays or binders may be made of eight inch timber, hewn on two sides; but iron has a much better appearance. The cross binders *b, b, b, b*, are made of one inch square

wrought iron bar, either with head and screw, or with head and key; either will answer the purpose. The distance between two binders should not be more than four feet, and, if possible, less than that; *c, c, c,* are draft-holes, just the size of a common brick cross section, for the regulation of the fire; these must be closed, or opened, as the charring of the wood progresses. *B*, Fig.

Fig. 28.



Section of wood-charring oven.

28, is a cross section of the oven; in the brick arch *d*, a square opening *e*, eighteen inches wide, is left; this opening may be shut, when necessary, with an iron plate. At each end of the oven there is a door *f*, large enough to admit a man with a wheelbarrow. These openings serve the purpose of charging the oven, and

drawing the coal. A far better arrangement than these small doors at each end of the oven is to shut one end entirely with brick, and leave the other entirely open; or at least to leave an opening sufficiently large to permit the entrance of a horse and cart, and then to shut this opening with large double doors, secured inside by a heavy coating of loam. The bottom of the oven is covered with sand, or, what is still better, coal dust well pounded down. The perfect air-tightness of the brickwork is of the highest importance; the bricklayers require to be watched, as well as instructed. Common brickwork will not do. All the joints, in addition to being completely filled with mortar, should be regularly broken. The wall should be one brick and a half thick. Common mortar of lime and sand should not be used, for the acetic acid of the wood dissolves the lime and leaves the sand alone in the joints. Common loam, mixed with coal tar or sea salt, makes an excellent mortar.

The inside of the oven should be well smoothed, and all the joints filled. Coatings of coal tar are the best covering for the outside; these, besides securing the

durability of bricks and mortar, close small crevices, and strengthen the walls. Such ovens are usually built twelve feet in width, twelve feet in height, and fifty feet in length; seldom larger. An oven of this size ought to contain fifty-five cords of wood.

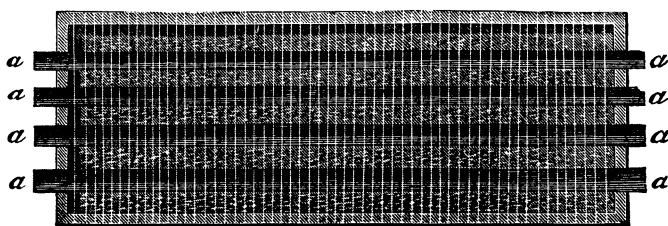
The wood is laid flat, and piled row by row until the oven is filled. In the centre, from the hole *e*, a channel or chimney is left, about twelve or fifteen inches in diameter, for the purpose of enabling us to kindle the wood properly at the bottom. Some kindle at the draft-holes *c*, *c*, or at the doors at both ends; but the former is the preferable plan. After the oven is filled, the doors closed and well secured, the air-holes shut with a brick-bat, and every access of air into the oven prevented, a fire of charcoal brands or of dry wood may be thrown down through *e*; this will kindle the wood at the bottom of the pile. After the fire is fairly started, the chimney may be filled with dry cord wood; and in the mean time, on each of the four corners an air-hole is opened. Within six or eight hours the fire in the interior will be sufficiently spread to permit the opening of a few air-holes at both ends of the kiln. When the heat draws near, these ends may be shut, and some air-holes opened along the sides. By alternately shutting and opening air-holes, according to necessity, the oven will be sufficiently heated within forty-eight hours. This may be determined by the escape of brown smoke from *e*. After the steam at *e* ceases, and a dark yellow or brown smoke escapes, the heat in the interior is sufficiently developed to char that wood which is not touched by fire. The top hole *e* may be tightly closed either with an iron plate, or with a board, covered with moist loam. The smoke will now escape from the air-holes around the oven; these must be gradually closed one after another, and then secured by shutting the joints with moist loam. Three days must elapse before the charcoal is sufficiently cool to be drawn; if an oven does not cool in that time, either air-holes must be open, or the brickwork cannot be tight. To remedy this evil, the outside of the oven should be covered with a thin

wash of loam water mixed with sea salt, that all invisible cracks and joints may be closed. After this wash is dry, it may be covered with a good coating of coal tar. If the oven is in proper order, the cover on *e* may be taken off, and a few air-holes opened. Should no smoke or heat escape, within two hours, from *e*, the doors may be opened, and the coal drawn, and carried off.

Ovens of this description afford great advantages where a good supply of wood can be obtained. They furnish a strong and coarse coal for the blast furnace, but do not answer so well for forge coal. Forge coal is best made in pits or kilns.

Where wood is scarce, and economy of fuel, therefore, an object, brown charcoal, or brown wood is frequently used in the blast furnace. The wood, in this case, is only strongly dried or roasted. For this purpose, an oven about twenty-five feet long, half the size of the first is required. Its form is similar to that of Fig. 27, with this difference, that it contains no air-holes; while four flues in the bottom, made of brickwork, run its whole length. These flues are eighteen inches wide, arched at the top. In the top of the flues, at intervals of two or three feet, draft-holes are left, through which a large quantity of heated air can pass.

Fig. 29.



Ground-plan of a wood-drying oven.

Fig. 29 exhibits a ground-plan of the flues; the channels *a, a*, project about a foot at each end, to permit the closing of the doors with safety. The oven is charged with wood, as in Fig. 27; but it is without a chimney in the centre. After the doors are closed, and everything

else well secured, fire is kindled at *a, a, a, a*, and kept going with sawdust, green chips, or with any slow burning fuel. Peat or brown coal will answer quite as well as anything else. The fire must be so regulated as to let a large amount of air pass over it, get heated, and pass through the wood. By this method, wood will dry very fast; in thirty-six hours, twenty-five cords will be in a condition fit to be drawn, in case the manipulations have been properly conducted. But great care is to be taken that the temperature of the fire is kept so low that the cord-wood cannot catch. Should such an accident happen, the top is to be closed directly, and the fire-places shut up.

How far the wood should be charred, depends on circumstances. A charring sufficient to permit the breaking of the billets by hand, will be indicated by a dark brown color of the wood; such wood works well when mixed with charcoal or coke; it keeps the blast furnace open, and bears a stronger blast than charcoal alone. In France, Germany, and Russia, brown charcoal is frequently used.

General Remarks.—The charring of wood is, to the manufacturer of iron, a subject of the greatest importance. His business requires a strong, compact, heavy charcoal. Charcoal obtained by the action of a rapid fire in close vessels, or in the open air, is light, spongy, and friable, and unfit for his purpose. Wood charred in an iron retort furnished, according to a French experimenter, within three hours, eighty-eight parts of charcoal; within four hours, ninety parts; and within five hours 113 parts. Beyond this time, instead of an increase, there was a decrease of charcoal. It is proper to remark, that a well-conducted kiln furnished, on the same principle, 106 parts of charcoal; this result clearly shows the utility of kiln charring. But there is a limit in both cases. Too quick and too slow work are equally injurious. We should always be governed by the following facts in our operations: If the charring is pushed too fast, or if, from the kindling of the wood, it is too lively, the coal will be small, light, and the yield will be mea-

gre. If, on the contrary, charring proceeds slowly, the coal will be light and friable; though the yield, if the cover has been kept tight, will be good.

The yield varies considerably, according to the quality of wood, and the kind of timber. Mr. Mushet gives, as the result of charring on the small scale, with due consideration of the form of the pieces of wood, the following comparison, in which one hundred parts in weight of dry wood were taken for each trial:—

Mahogany	25.4
Chestnut.	23.2
Oak	22.6
Walnut	20.6
Beech	19.9
Sycamore	19.7
Pine	19.2
Ash	17.9
Birch	17.4

So uniform a result depends, however, very much on the uniform structure and dryness of the wood; conditions not always at our command either in the woods or in the yard. Season, and the age, as well as the dryness, of the wood, influence greatly both the yield and quality of coal. Experience has taught us this fact; and it is beautifully illustrated in the following table by M. Berthier, a French chemist. The wood used in his experiments, where not otherwise mentioned, was thirty-two years old, and was charred in common kilns, under the same conditions. The table shows the percentage of coal yielded in one hundred parts:—

	Coal.	Brands.
Green red beech, charred shortly after being cut	19.7	0.6
Green red beech, charred shortly after being cut, peeled	23.0	0.3
Dry red beech and oak, of two years' standing	24.0	0.3
Dry red oak, and oak of two years' standing, peeled	25.7	0.3
Green white oak, charred three months after being cut	22.4	0.3

	Coal.	Brands.
Green white oak, charred three months after being cut, peeled	21.2	0.3
Red beech and oak, cut in January, and charred in August	23.4	0.5
Green red beech, charred immediately after being cut	12.9	0.3
Green red oak, charred immediately after being cut	13.5	0.4

We thus see that one hundred pounds of wood in kilns produce on an average, twenty pounds of charcoal. In retorts and ovens, the amount seldom exceeds twenty-two pounds. The advantage, therefore, of employing ovens, apart from other considerations, is not great ; but this is the ground of preference. Ovens are advantageous where wood can be transported on water ; this transportation charcoal cannot bear without injury. Charcoal absorbs water and gases in large quantities ; and what it gains in specific gravity it loses in combustibility ; still, it is generally preferable for making iron. On what hypothesis this anomaly is to be explained, we are unable to say. We simply mention it as an established fact. Charcoal will absorb a large amount of water within the first twenty-four hours ; but, after that time, very little. Different kinds of charcoal absorb water in different quantities, to wit :—

Charcoal from	lignum vitæ	gained	9.6	per cent.
"	fir	"	13.0	"
"	box	"	14.0	"
"	beech	"	16.3	"
"	oak	"	16.5	"
"	mahogany	"	18.0	"

That water cannot be the cause of improvement, is evident. To assist those who desire to investigate this subject, we subjoin a table on the absorption of gases by charcoal within the first twenty-four hours after charring. One hundred parts of charcoal absorbed

Ammoniacal gas	90	per cent.
Muriatic gas	85	"
Sulphurous acid	55	"
Sulphuretted hydrogen	55	"
Nitrous oxide	40	"
Carbonic acid gas	35	"
Bicarburetted hydrogen	35	"
Carbonic oxide	9.42	"
Oxygen	9.25	"
Nitrogen	7.50	"
Carburetted hydrogen	5.00	"
Hydrogen	1.75	"

Many iron manufacturers desire to realize the products of distillation ; but the deficiency in the quality of the charcoal more than counterbalances the whole gain of the distillation. The iron master will employ his time far more profitably by cultivating the charring for the production of charcoal alone.

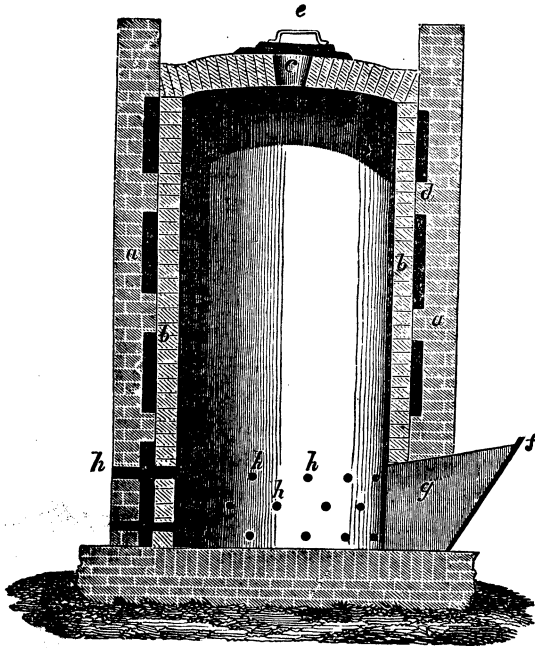
The time best adapted for charring in the woods, is from May till October inclusive. During the summer, the air is bland, the roads good, and the furnace yard dry ; considerations of great importance. A bushel of five pecks, or 2675 cubic inches, of fresh charcoal, made of beech, oak, maple, and hickory, ought to weigh from fifteen to sixteen pounds ; a bushel of pine coal, from ten to eleven pounds ; and the prices paid for charcoal should vary accordingly.

Charring of Turf or Peat.

The charring of peat is far more easily effected than the charring of wood, partly on account of its square form, partly on account of its chemical composition. In pits, the charring of peat is not difficult, if we pursue the same method as that pursued in the charring of wood ; but we are forced to leave channels, or draft-holes, in the kiln, because the square pieces pack so closely, that, without this precaution, sufficient draft would not be left to conduct the fire. Turf or peat is generally found in considerable masses in one spot ; therefore the erection of char-ovens is no object of mere speculation, but affords

all the advantages of a permanent establishment. Char-ovens are comparatively small, and of course not expensive. We therefore shall omit a description of charring in pits, and shall proceed to describe a char-oven, which has been used for many years, and consequently sufficiently tested. Fig. 30 represents a vertical cylinder,

Fig. 30.



Char-oven for peat.

built of bricks, with a round cupola on the top; it is nine feet high, and five feet and a half in diameter, which gives 250 cubic feet capacity. The inner cylinder *b*, built of fire brick, is surrounded by a mantle *a* of common brick, and the space left between both is filled with sand. Sometimes a brick *d* runs all the way through, to bind both walls; on the top is a round opening *c*; *e* is an iron plate to close the draft-hole *c*; *f* is a board, or a piece of sheet iron to hold the sand, which is used to shut the air out, by filling the space *g*. The fuel is filled in at *c*, and

packed closely, with the exception of a few channels at the bottom, which correspond with the little draft-holes *h, h, h*. A vertical chimney is left in the centre, at which gases may escape. The fire is put in through *c*, down to the bottom; and when it has spread so far as to show itself at the holes *h, h, h*, these holes are shut by a stopper of clay. When the smoking at the top ceases, all the openings, as well as the top, are to be shut; and the oven left for cooling. Four or five days will, in most cases, be sufficient to burn an oven of peat charcoal. The holes *h, h, h*, can be formed of old gun barrels or iron pipes; bricks or earthenware pipes are very apt to break.

Turf or peat charcoal is an excellent fuel, but expensive; it burns freely, and produces a fine heat. In Styria, sheet iron and reheating furnaces are heated by it: and in Bohemia, Bavaria, France, and Russia, it is extensively used in the blast furnaces, and produces in most cases, very liquid, lively iron. Good turf or peat coal is superior to charcoal in the blacksmith's fire.]

Peat has, of late, been found to exist in so great quantities, especially in New England, and of such a quantity and quality yet undeveloped fully in other States, that some method will yet be adopted for rendering it cheap and available for the furnace. The amount in mass alone is estimated at 120,000,000 cords. Even the *muck*, which is at present considered only fit for a fertilizer, may by proper cleansing be used for burning. But the furnaces wherein much of the peat, now treated as useless, might be used with good effect, are the reverberatory furnaces, wherein the carbonaceous material of the peat, well selected, is so much freer from sulphur than are harder coals, and so nearly allied to charcoal, that good effects may be reached in deoxidizing ores which cannot by the use of harder coals or cokes.

The round form adopted in preparing the pressed peats of Ticonderoga, N. Y., seem greatly adapted to all furnace operations.

Analysis affords—carbon, 58.09; hydrogen, 5.93; oxygen, 31.37; ashes, 4.61=100. The traces of phosphorus present, due to animal decomposition, are not necessarily

in such quantity as to injure the iron, especially when the new method by Siemens's regenerative furnaces is used. See *Siemens's furnace*.

Charring of Brown Coal.

[Brown coal is so imperfect a fuel in most cases, that it scarcely ever admits of being charred; but the best lignite of Europe is charred, though only with limited success] The discoveries of this coal in the Western Territories may yet be made available for metallurgical purposes, when the same ovens spoken of in the last section, will be found to answer all purposes of charring brown coal or lignites.

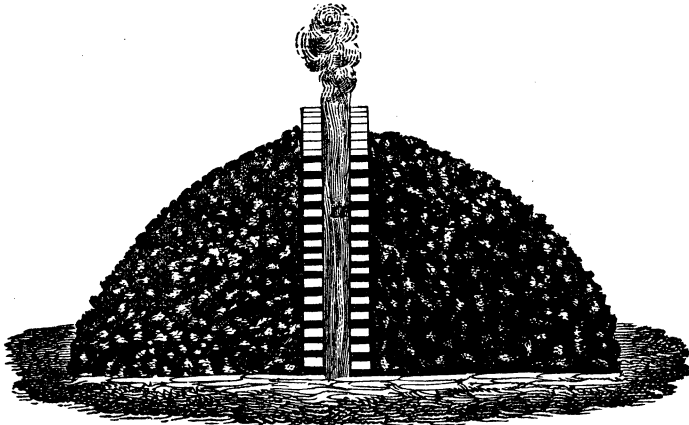
Charring of Bituminous Coal, Coke.

[The manufacture of coke for blast furnace purposes is generally carried on in the open air, either in round heaps or rows; the latter mode is generally preferred. Coke burned in ovens will answer for that which is used in the furnace of locomotives, or for the purpose of generating steam; it is even useful in a foundry cupola oven; but in the blast furnace, or even in the refining fire, it ought not to be applied, because of sulphur as we shall presently explain.

Coking in heaps is almost the same as charring wood in heaps; the main difference is that the heaps are smaller. For the purpose of coking in heaps, a level spot in the yard is selected, or a level staked out and prepared; a temporary chimney of common, or even of fire brick is erected, with alternate holes, some of which are especially necessary at the base. Around this chimney coarse coal is piled; the bottom, or level, is covered with coarse coal, in which draft-channels must be left; coal may then be thrown on as it comes; but the coarse coal must be put in the centre of the heap. The height is of but little consequence, and may vary from three to six feet, according to convenience. But the chimney is to be built sufficiently high to reach over the top of the coal pile. Fig. 31 represents such a kiln or heap; *a* is

the brick chimney. After the heap is ready, fire may be kindled around the base at different places, particularly near the horizontal channels; and the whole pile may then be slightly covered with coke dust. The fire

Fig. 31.



Coking in heaps.

will spread rapidly, and in a few hours, will reach almost to the centre. A few air holes may now be made in the cover with an iron bar, through which the heat and smoke may have vent. These air-holes should be frequently renewed, because very bituminous coal is apt, by swelling, to close them. If the fire has been kindled in the morning, the heap will be in a good heat towards evening. It may then be covered heavily with dust, and the fire all around the heap choked. But the chimney is to be left open. The next day, or, at furthest, after the third day, the coke is ready for use. The object of leaving the chimney open is to retain a slow, but strong heat, as long as possible, in the heap, without wasting fuel. By this means, as much as possible of the sulphur contained in the coal will be expelled. If the ground where the heap is piled is somewhat moist, the hot steam arising from the ground will carry off a large portion of the sulphur in the form of sulphurous acid, in case the heat is not too great, and there is but little access of atmospheric air.

If the heat is too great, and if there is too great an access of the air, this conversion of the sulphur does not take place, and the sulphur remains in the coal. The same circumstance happens if the chimney is closed, and no circulation of air or steam thereby possible. Coking in heaps furnishes generally a strong coarse coke, but not so free of hydrogen and sulphur as that furnished by the following arrangement. The mass of coal is generally too large to permit the necessary circulation and contact of watery vapors. This is doubtless the cause of the inferiority of the coke.

Coking in rows, or long heaps, is a preferable mode of making coke; these rows are sometimes one hundred feet long, seven or eight feet wide, and three feet high. To coke in rows, a yard is to be levelled sufficiently large to hold as much coal as is required to keep the furnaces in operation. Along, or all around, this yard, it is advisable to have a ditch dug, which will hold a regular supply of water throughout the year; this water ought not to fail during the driest seasons. A row is started at that end of the yard most convenient for the transportation of the raw coal, and directed in a straight line towards a point on the opposite side of the yard. Should there be a deep covering of coke dust all over the yard, a kind of ditch, as broad as the coal pile is designed to be, may be prepared by scraping the dust from the middle, and drawing it towards the spaces between the rows. This ditch will indicate the direction in which the coal is to be laid, and will bring it close to the moist ground. The scraped coke dust is afterwards used for covering the heap. The coal arranged as in the above case. Due attention should be paid to placing air-channels, or draft-holes, at the bottom, and to throwing the coarse coal in the centre. At a distance of seven or eight feet from each other, tapered posts, seven or eight inches in diameter, are fastened in the ground, around which the coarsest coal is arranged. These posts or poles are removed before the heap is fired, and are designed to form chimneys, for the free vent of gaseous matter, and the increase of draft. When the pile extends twenty feet, or more, and it is covered with small coal, slag, or coke

dust, fire may be put to the heap at different places near the air-holes; and the row may then be continued. In this way, it will happen that coke is drawn at one end of a row, and coal is set at the other. After fire is kindled, and the heat extended to the centre, the pile may be covered more closely, with due attention to leaving some air-holes near the top; and in case these holes are shut by the expansion of the coal, they should be reopened by means of iron bars run down to the centre of the pile, or at least to the fire. When the yellow flames of carburetted hydrogen cease to be visible, the heap and air-holes may be closely covered by coke dust, and the coke left to cool. This method of making coke for the blast furnace has, thus far, been preferred to any other method. For this preference, the following reasons may be assigned: the small body of coal on fire at one time; the large surface of ground it covers, thus presenting unequalled facilities for the circulation of watery vapors through the hot coke; and the chance which it affords of retaining the heat till the advantages of steam are produced. For these reasons, a water ditch around a coke yard is required to keep the ground moist: besides, water is frequently needed to choke the fire where it continues too long in the heap, and thus to drive the steam through the hot coke. For the same reason, a yard does not make good coke if it is covered too thickly with coke dust.

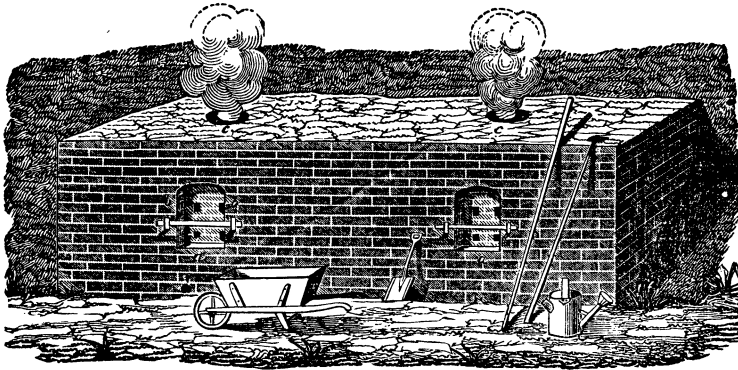
Thus far, the making of coke is accompanied with no difficulties; still, some rules require attention, if we expect both the quantity and quality of our work to prove satisfactory. In some cases, the fire should be suffered to play through the whole heap before it is covered with dust. This applies particularly to slack, small coal, and to very bituminous coal, as well as to the whole of the western coal fields; for, if the coal is apt greatly to swell, it will very likely choke the fire. In setting the heaps, too much attention cannot be paid to placing the coal inside in as open a manner as possible. The more the coal is inclined to swell, or, the more bitumen the coal contains, the more carefully should this direction be followed. The coarse coal and lumps are to be set edge-

wise; that is, the direction of the cleavage is to be vertical, or, what is the same thing, directly contrary to its natural position in the vein. If the coal is dry, if it is not very bituminous, fire may be kindled in the chimneys after the poles are removed; but where it is bituminous, such an arrangement would disturb the draft. Where small or very bituminous coal is to be coked, it may be advisable, in some cases, to erect, in the centre of the row, chimneys of brick, distant from each other five or six feet, and to leave only draft-holes at the base, because such coal is very apt to burn outside or at the surface, while the bottom part and interior are left unburnt.

Coking in Ovens.—Cases may occur where coking in ovens may be permitted, even for blast furnace coke; as, for instance, where a very brittle coal, but free of sulphur, is to be charred. But these cases are rare, at least in the coal fields at present worked; for all our coal, when compared to that employed in the blast furnaces in Europe, may be considered more or less sulphurous. However that may be, coke ovens are practicable; at least, they are at present in use in the Pittsburg coal fields. A large part of the coke used in cupola ovens and refining fires in the Western States is made in ovens. Coke ovens of various forms have been erected, sometimes with regard to quality, but most generally to quantity; and for the latter purpose they have been brought to great perfection. In our case, quantity is of secondary consideration; the obtaining of coke, free of bitumen and sulphur, is the object at which we aim. All the various coke ovens are constructed mainly upon one principle; that is, they are built in the form of a common bake oven, and generally of capacity sufficient to receive a charge of two or three tons of coal at once. Some are round; others egg-shaped; and at the Clyde Iron Works, in Scotland, the hearth is square. *Ure's Dictionary of Arts and Manufactures* contains a description of an excellent arrangement for coking coal, erected for the use of the locomotive engines of the London and Birmingham Railway Company; but we doubt the utility of such ovens

in iron establishments, for we cannot believe that the large quantity of coke yielded is of quality sufficiently good for the manufacture of iron. In Germany and France, coke ovens have been built of admirable construction, as far as the saving of fuel is concerned; but iron masters who require a good article, burn coke in the open air. Of the different forms of coke ovens, we should prefer the most simple; such a form is at present in general use in the neighborhood of Pittsburg; the form and dimensions of such an apparatus are exhibited in the following figures. Fig. 32 represents a double coke oven, in front view, built of stone or common brick,

Fig. 32.

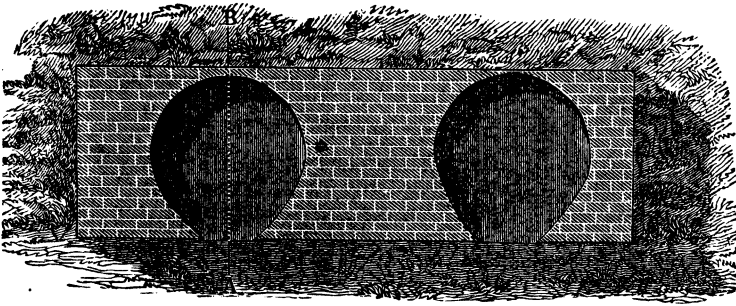


Front elevation of a Pittsburg coke oven.

against the slope of a hill, so that the coal may be unloaded on the top of the oven; it is accessible by railroad, or common carts or wagons. Fig. 33 is the ground-plan of the twin oven; it shows the laying out of the hearth, which is ten feet long, and ten feet wide, with corners rounded, so as to prevent the coke sticking in them. Fig. 34 shows a cross section of one oven in the direction of *A, B*, Fig. 33. The same letters are used to designate the same objects in the different figures. *a, a* represent doors, two feet in width, designed to be shut with brick and clay when the oven is to be filled with coal. Some openings are left in the temporary brickwork

of the door, to regulate the fire; but these are to be shut when the fire has penetrated through the mass of coal.

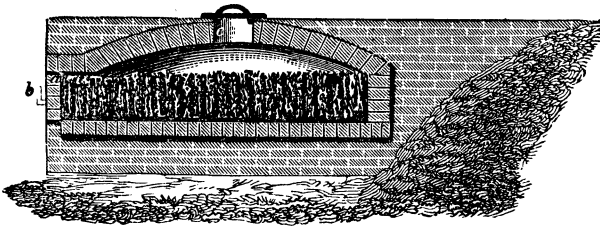
Fig. 33.



Ground-plan of a Pittsburgh double coke oven.

b, b are iron hooks, walled in, into which an iron bar from an inch to an inch and a half square is placed; this bar serves to strengthen the temporary brick filling in the door, and to prevent the throwing out by the swell-

Fig. 34.



Section of a Pittsburgh coke oven.

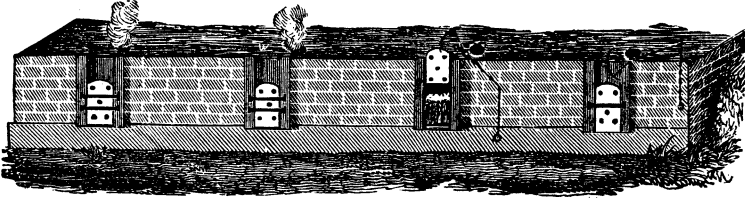
ing of the coal: *c*, Fig. 34, is a round hole, left in the top, through which the disengaged gases may escape; this hole, from twenty to twenty-four inches in diameter, is left open until all the bitumen of the coal is driven off, after which it is to be shut by a cast-iron plate, and luted with clay. The interior of the furnace is to be built with fire brick and fire clay mortar; the rough wall either with stones or common brick. Such an oven has a capacity of from seventy-five to eighty bushels; it will fur-

nish from Pittsburg slack coal nearly one hundred bushels of coke. After it is finished by the masons, and ready for use, some wood is thrown on the hearth towards the door, which is to be repeated each time the oven gets cold; the door is then walled up, and the coal thrown in through the hole at the top, and spread uniformly over the hearth. Eighty bushels of coal will cover the bottom about twelve inches high, which will rise to fifteen inches after being burnt. The top arch, therefore, should be sufficiently high from the bottom to permit the swelling of the coal and the breaking up of the solid mass of coke. The height of the arch from the bottom is generally from twenty to twenty-four inches; in the centre, thirty inches. When the coal is properly spread, fire may be applied at the door and top; after the first and second heats, it needs no kindling, for the bottom and sides of the oven are sufficiently warm to kindle the coal. After ten or twelve hours, the bituminous gases are mostly expelled; the top can then be closed, that the oven may cool; eight or ten hours will be sufficient for this purpose. Though the coke may be redhot, there is no danger of its further burning. The door is now opened, and the hot coke removed in iron wheelbarrows. This is frequently quite a hard task; and a set of long and strong crowbars, besides some long iron scrapers, are needed in every establishment of this kind, to facilitate operations, and to prevent any delay of the regular work. The coke of the first heat is generally raw at the bottom, and spongy at the top; but the second and following heats improve as the oven gets better. We may say, generally, the hotter the oven, the better the coke. Good coke ought to exhibit a uniform crystalline texture throughout the whole mass, and when cold, should sound like fragments of stoneware.

One of the most common arrangements of coke ovens, in the Old World, is exhibited by the following diagrams: Figs. 35 and 36. The oven here represented is that of the Northumberland and Lemington Iron Works upon Tyne. Four ovens are shown to be in a line; this arrangement is preferred because it keeps the heat

together and saves masonry. The hearth of the oven is a rectangle, ten by twelve feet; and from the bottom to the arch the height is three feet. The rough walls are of common brick, two feet thick, and the lining of fire

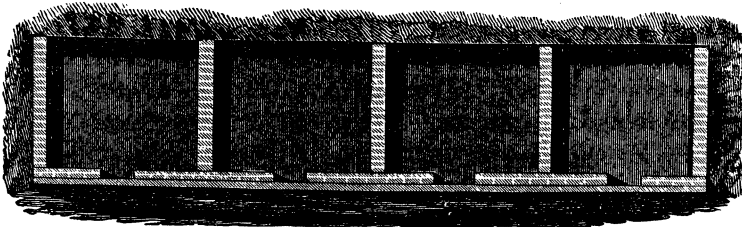
Fig. 35.



English coke ovens.

brick. At the centre, on the top, is a round hole, two and a half feet in diameter, through which gases escape. The doors are three feet square. On the top is a cast-iron frame, with two bars or cleats; between these a door slides. This door is of wrought iron, filled with brickwork, which sliding upon the above frame, may cover the gas hole, or be withdrawn at pleasure. The same arrangement is used to shut the doors, with this

Fig. 36.



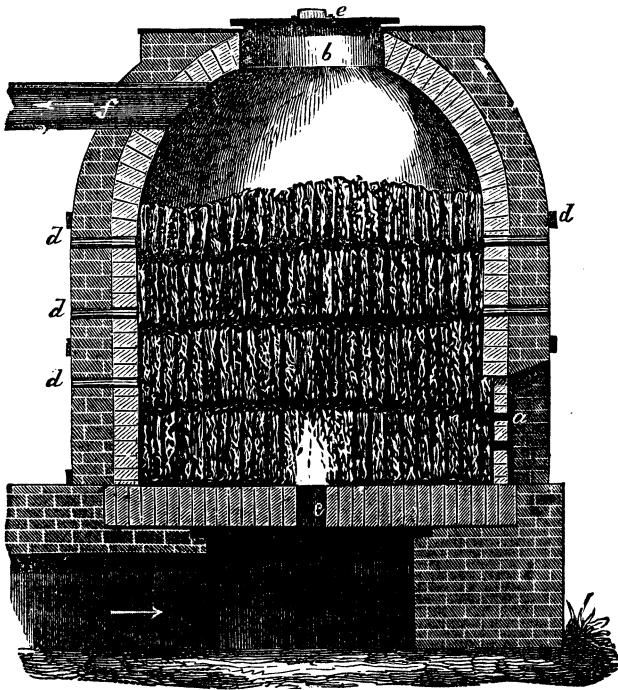
Ground-plan of English coke ovens.

difference, that the door is vertical, and balanced by a lever. In the brick filling of the door, are a number of draft-holes, through which air can have access to the burning coal.

This arrangement, in its principle, differs not in the least from the Pittsburg arrangement. But the execution of the latter is more perfect than that of the former,

though at the same time more expensive, and less suited to our country. This oven is charged with from two to three tons of coal. The manipulations are the same as those at the Pittsburg ovens. In countries, Germany and France, for instance, where coal tar is of value, and its gathering yields profit, coke ovens have a different form. As coal tar may be highly valuable in some parts of the United States, we shall describe one of these ovens. Fig. 37 represents a cross section of a coke oven which,

Fig. 37.



German coke oven, for gathering coal tar.

for many years, has been in operation in Silesia, eastern Germany, and may be considered of an improved form. This oven is about nine feet high; it is of a cylindrical form, and is four feet in diameter; the interior is built of fire brick, and the exterior of common brick or stones bound with iron hoops. The coal is put in partly through the door *a*, and partly through the top hole *b*. Care is

taken to lay coarse coal at the bottom. The bottom part of the oven forms a kind of grate, for the holes *c, c, c*, are left open, in which iron pipes are walled in; there are seven of such holes in the bottom. The holes in the side wall *d, d, d*, are draft-holes, secured by iron pipes. The top is covered with an iron plate in which the lid *e* fits. The tar and gases are conveyed by the iron pipe *f* into a reservoir, or tar barrels. The pipe is conducted through cold water, that the tar, during summer, may condense; but in winter, the atmospheric air is sufficiently cool to condense all the tar which escapes from the oven. Coarse coal is put in the bottom part; upon this is thrown slack coal. If the oven is about two-thirds filled, fire is kindled, and the door *a* shut with brick and clay mortar. The fire may be safely left to burn, and the top plate *e* may be put on and luted with clay. After eight or ten hours, the upper row of holes *d* will appear brightly red, and may be shut. After that time has again elapsed, the second row from above may be shut. Twelve hours more may elapse, when the lower holes, becoming bright, may be closed. By this time, tar almost ceases to be produced. Then, after shutting carefully all the holes the oven may be left to cool. This cooling will take place in the course of the next twelve hours.

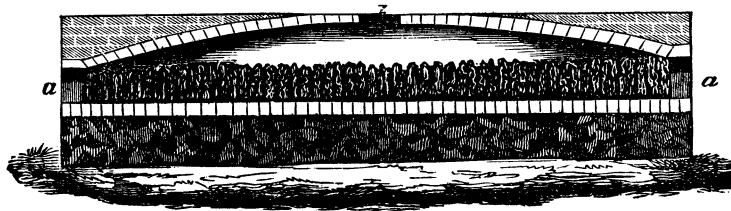
The charge in such an oven amounts to two tons of coal. Two charges may be made during one week, if the coke is drawn in time. The coke thus produced is very hard and compact, and may be considered superior to any other; but the manipulations in this oven are both expensive and troublesome. One bushel of coal furnishes three-fourths of a bushel of coke; and one hundred pounds of coal produce fifty-three pounds of coke, and five gallons of tar. The bituminous coal of upper Silesia is referred to. One hundred pounds of this coal furnish from forty-five to forty-seven pounds of coke, when burnt in the open air; while one bushel of coal furnishes nearly one bushel and a quarter of coke.

In the neighborhood of St. Etienne, in France, a kind of double coke oven is in use, which is worthy of notice. Its form is, in the main, the same as that of any other

coke oven, but differs in being of larger dimensions, and in having two doors for drawing, instead, like other ovens, of but one.

Fig. 38 represents a double oven ; *a, a* are two opposite doors. The bottom is formed of hard rammed fire clay ; its top and sides are of fire brick ; the rough wall either of common bricks or stones. The chimney *b* is

Fig. 38.



French coke oven.

eighteen inches in diameter, and the whole arch is covered with sand, to keep in the heat. Its arrangements, in other respects, are the same as those of other coke ovens. It contains a charge of from three to four tons of coal. The hearth ought to be sufficiently large to take this amount of coal, piled ten inches high. The centre of the arch may be four feet from the bottom.

Coking in Iron Retorts.—By the distillation of coal in iron retorts, no coke can be made serviceable for the manufacture of iron. Coke thus made is always light, spongy, and never free from bitumen or sulphur ; qualities which render it unfit for an iron manufactory. We shall, therefore, dispense with the consideration of this method.

General Remarks on Coking.

The making of good coke is, to the manufacturer of iron, a very difficult task. Good coke ought to be of a silvery-white granular appearance, and compact ; it ought to sound like good crockery ware, and should be free of bitumen, hydrogen, and sulphur. Good color and compactness may be secured in various ways ; but

the other qualities are not so easily secured. Hard, compact coke will be obtained from large piles, either in ovens or in the free air, if the fire is brisk and the coverings heavy ; but coke made in that way always contains more sulphur and hydrogen than it should contain. A large body of coal, under a slow fire, furnishes light spongy coke, but more free of sulphur and bitumen than under a quick fire. A medium heat serves better than either extreme. Where the body of coal is kindled, the heat ought to be kept as low as possible ; the longer the heat is applied, the better will be the result. By this means most of the sulphur, as well as the hydrogen, will be expelled. When we have ascertained that no more sulphur escapes, the heat may be raised by giving free vent to the gases through the air-holes. If a current of steam can possibly be passed through the glowing coal, during the first stages of coking, it should be done. In the yard, where we coke in piles, this may be easily effected, by keeping the ground moist, and laying the coal as closely as possible upon it. But in ovens this is more difficult, because in them it is not so convenient to change and regulate the fire.

If the bottom of the ovens is made of clay laid upon sand, and if we are able to regulate the moisture of this sand, a great deal may be effected. In this manner the French oven, Fig. 38, is constructed. This is the only practicable method by which watery vapors can be made to pass through the hot coal—a matter requiring attention in the first stages of the operation. If the hydrogen is expelled by a too lively heat at the commencement of the operation, the sulphur is very apt to remain, and cannot be driven off ; for carbon and sulphur, combined by strong heat, cannot be separated, except by their mutual destruction. We cannot pay too much attention to this subject, for upon it depends the success of the blast furnace operation. Sulphurous coal, by improper treatment, will produce sulphurous coke, and consequently sulphurous metal, which, in all subsequent manipulations, will be injurious, troublesome, and expensive. By sprinkling a little water over red-hot coke, drawn freshly from the oven or pile, we may ascertain whether it contains

sulphur. If the odor of sulphuretted hydrogen, or rotten eggs, is emitted, the presence of sulphur is indicated. If the hot and melted iron in the pig bed throws off sulphur, the coking of the coal requires our closest examination. In some establishments, workmen have been advised to sprinkle water over the red-hot coke, which may be done from the nose of a watering pot, partly with the object of expelling the remaining sulphur, and partly with the object of extinguishing the fire.] Care should be taken not to throw too much water upon the pile, and it should be done, if done at all, in the finest spray.

Perhaps that method is as good as any method of out-door coking, which is adopted at Johnstown, Cambria County, Pa., and which is as follows: The "pits" are made upon level ground, and are about 36 yards long, and 4 yards wide, with a floor running the entire length. Allowance is made for one chimney flue to every ten feet of horizontal flue, that is, measuring from centre to centre of flues. The coke-hands begin by putting large pieces of coal down upon the floor in two parallel lines, leaving intervals for the side chimney flues; this is done for the whole length of the intended pit, 36 yards. About 3 feet from the ends of this line are the centres of the first and last cross flues, which are generally about ten to twelve inches square, after these the cross flues are about 6 feet apart throughout the entire length intervening between the two end flues. The cross flues are the ones into which the fire is placed when the heap is complete. The long flue is then covered, except where the main and centre chimney flue rises—the right angle, or cross flues also are covered, and then all open spaces are filled in on the angles completely out to the width, 4 yards, and then builded up vertically to the height of $2\frac{1}{2}$ to $3\frac{1}{2}$ feet, and covered with smaller coals, dust, or ashes, and the fire applied to the openings of alternate cross flues. It generally requires five to six days, according to weather, for the coking of this mass. After the fires are lighted, a man is constantly on the watch to regulate by stopping up the cross flues, or by opening them according to rapidity of firing. Irregularity is due to weather, *i.e.*, to rain, direction and quantity of wind.

If the coal was packed uniformly and covered properly with slack coal or ashes, the coal burns regularly, and when coked it is smothered and water thrown upon it from a hose, until cool enough for carrying off.

[The yield of coke varies according to differences in coal. In England, seventy-five per cent. by weight, and 120 by measure, is considered a good average yield. On the Continent, coal varies greatly. That which is very bituminous yields fifty-five per cent. weight in ovens; and from coal less bituminous, the yield varies from sixty to seventy-five per cent. Professor Johnson, of Philadelphia, in his *Report to the Navy Department of the United States on American Coals*, has given us some highly useful notes on the amount of coke produced from different kinds of American coal. We extract the following data:—

	Per cent. coke.	Remarks.
Cumberland, Md. . . .	78 & 72	The first by slow, the latter by fast coking.
Blossburg, Tioga Co., Pa. .	83	
Ralston, Lycoming Co., Pa.	86	Little sulphur in this coal.
Karthus, Clearfield Co., Pa.	88	
Summit Portage R. R., Cambridge Co., Pa. . . .	79	Very sulphurous, containing 10 per cent. of ashes.
Deep Run Mines, near Richmond, Va. . . .	80	Upwards of 11 per cent. ashes.
Henrico Co., Va. . . .	75	Scarcely any sulphur; very little ashes.
Creek Coal Co., Chesterfield Co., Va. . . .	68	
Clover Hill Mines, Appomattox River, Va. . . .	68	Adapted to manufacture of iron.
Midlothian Coal Co., Va. .	66	“ “ “
Above Petersburg (20 miles)	....	Resembles Clover Hill, and same quality.
Nova Scotia	62	Very sulphurous; Pictou coal better quality.
Cannelton, Indiana . . .	64	Not much ashes or sulphur.
Pittsburg, Pa. . . .	68	Hardly any sulphur and little ashes.
Wheeling, Va. . . .	57	Earthy matter 3.9; more sulphur than Pittsburg, but good for iron.
From Missouri	57	Scarcely any earthy matter, and little sulphur.

All the above experiments of coking were made in a closed vessel. The yield in coke ovens, or in the open air, is not so large. The coal of the Western States is generally of good quality.

Coals of inferior quality, or those whose composition prevents their application in the blast furnace, we have forborne to notice. A great variety of coal from our large western coal fields was not sent to Prof. Johnson. All the above experiments of coking were made in a closed vessel. The yield in coke ovens, or in the open air, is not so large. The coal of the western States is generally of good quality, particularly the veins lying above the extensive Pittsburg vein. In some mines the lower veins do not yield so good an article for the blast furnace, but this is not always the case.

Highly bituminous coal loses, on an average, from fifty to fifty-five per cent.; coal that is drier, from thirty to forty per cent., by being coked in stacks or heaps. Coked in ovens, the same coal will respectively lose from forty to forty-five and from twenty to thirty per cent.; that is, twelve per cent. more coke will be yielded in ovens than in heaps, or in the open air. Retorts, or closed vessels, furnish a still larger result than ovens.

Heat liberated by Fuel.

The term *heat* is used to denote a state or condition of a body which produces a specific sensation which all immediately recognize. The effects of heat, and its generation and liberation, are all with which we are at present concerned; hence, the definition of heat, specially applicable to our subject, is that "force, agent, or principle in nature, upon which depends the state of bodies as solid, fluid, or aeriform, and which is recognized by its effects in the phenomena of expansion, fusion, and evaporation." Heat is generated, or, properly speaking, liberated, by almost every chemical process; at least, by all those processes by which simple elements combine to form compounds. For instance, heat is liberated when oxygen, sulphur, and chlorine combine with the metals

or with carbon and hydrogen; or when each combines with the other. A knowledge of the amount (quantity), as well as the degree or temperature (quality), of heat, liberated during the process of combustion, and in various chemical actions; and an acquaintance, especially, with the heat liberated by destruction of fuel, are, to the enlightened iron manufacturer, absolutely necessary.

The *quantity* of heat liberated from fuel varies in different compounds; but it may be laid down as a rule, that the amount of heat is in a constant ratio to the amount of oxygen consumed by any given process, provided the oxidation is carried to the proper degree. A practical elucidation of this subject we shall presently furnish. We shall give first a series of theoretical experiments by which the amount of heat liberated, and therefore, the difference, or relative value, of fuel may be estimated. In these experiments, the relative value of wood and other fuel is estimated by weight:—

Analysis of Relative Value of Fuel.

	Per cent.		Per cent.
Linden, air-dried . . .	34	Ash, air-dried . . .	30
“ dried artificially . .	38	“ dried artificially . .	33
“ “ “ strongly . . .	40	“ “ “ strongly . . .	35
Beech, air-dried . . .	33	Pine, air-dried . . .	30
“ dried artificially . .	36	“ dried artificially . .	33
Oak, air-dried . . .	29	Poplar, air-dried . . .	34
“ dried artificially . .	30	“ dried artificially . .	37
Sugar maple . . .	36		

Another Analysis.

	Per cent.		Per cent.
Oak, air-dried . . .	31	Birch, air-dried . . .	31
“ dried artificially . .	39	“ dried artificially . .	39
Ash, air-dried . . .	33	Poplar, air-dried . . .	29
“ dried artificially . .	39	“ dried artificially . .	40
Sugar maple, air-dried .	32	Linden, air-dried . . .	32
“ “ dried artificially .	40	“ dried artificially . .	41
Beech, air-dried . . .	31	Pine, air-dried . . .	31
“ dried artificially . .	39	“ dried artificially . .	40

Value of Charcoal.

Poplar, maple, ash, average 68 per cent.; charcoal from other species differs but slightly.

Value of Peat.

	Per cent.
French specimen	18 to 34
German "	26 " 42
Irish "	28 " 62

Value of Peat Charcoal.

French specimen	40 to 58
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Value of Brown Coal.

French specimen	36 to 57
German "	41 " 58
Grecian "	36 " 52

Value of Stone Coal.

	Per cent.		Per cent.
Dowlais, Wales	72	Cannel Coal, Glasgow,	
Germany	70	Scotland	56
Newcastle, England	70	Cannel Coal, Lancashire,	
France, Grande Croix	67	England	53
Spain, Asturian	59	Germany, Silesia	48
France, St. Etienne	57	Austria, Lower Danube	43
Cherry coal, Derbyshire,		Durham, England	71
England	61		

Value of Coke.

	Per cent.
Coke from France	65
" " the Gas Works, Paris	50
" " Germany	64

Value of Anthracite.

	Per cent.
Pennsylvania	71
France	69
Savoy	60

The preceding tables are of European origin, and as they have been mostly drawn up by Berthier, they may

be relied upon as correct. We shall still further elucidate this subject by presenting some of the observations of Professor Johnson:—

*American Coal, and the Evaporative Power of
American Fuel.*

	Specific gravity.	Volatile combustible matter in one hundred parts.	Carbon in one hundred parts.	Earthy matter in one hundred parts.	Steam of 212° evaporated by one pound of coal.	Corresponding numbers of the preceding European tables.
<i>Anthracite.</i>						
Beaver Meadow, Pa.	1.6	2.38	88.9	7.11	10.4	66.8
Forest Improvement, Pa.	1.4	3.07	90.7	4.41	10.8	69.4
Lehigh, Pa.	1.5	5.28	89.1	5.56	9.6	61.7
Lackawanna, Pa.	1.4	3.91	87.7	9.25	10.7	68.8
<i>Coke.</i>						
Midlothian, Va.				16.55	10.3	66.2
Cumberland, Md.				13.24	10.3	66.2
“ Mining Company, Md.				12.40	11.2	72.0
<i>Bituminous Coal.</i>						
Maryland Mining Company, Md.	1.4	12.31	73.5	12.40	11.2	72.0
Cumberland, Md.	1.3	15.52	74.29	9.30	11.0	70.7
Blossburg, Pa.	1.3	14.78	73.41	10.77	10.9	70.0
Karthus, Pa.	1.2	19.53	73.77	7.0	9.8	63.0
Cambria Co., Pa.	1.4	20.52	69.37	9.15	10.2	65.5
Clover Hill, Va.	1.2	32.21	56.83	10.43	8.5	54.6
Tippecanoe, Va.	1.3	34.54	64.62	9.37	8.5	54.6
Pictou, Nova Scotia	1.3	27.83	65.98	13.39	9.7	62.3
Liverpool	1.2	39.69	54.90	4.62	8.2	52.7
Scotch	1.5	39.19	48.81	9.34	7.7	49.6
Pittsburg, Pa.	1.2	36.76	54.97	7.07	8.9	57.2
Dry pine wood				0.3	4.7	30.2

The data in this table have been deduced from direct experiments made on the steam-boiler, and therefore are only measurably applicable to our case. In the iron manufacturing apparatus, heat is generated, and escapes at a far higher temperature than that of a steam-boiler.

The above-mentioned law, that the heat, liberated by combustion, is in direct proportion to the oxygen consumed, is one of the most useful inculcations of chemistry. By this law, we are enabled, if we know the composition of the fuel, to calculate the amount of heat it libe-

rates. The composition of various kinds of fuel has been given at the proper place. It is only necessary to present here the formula which will enable any one to calculate the quantity of heat evolved by any process of combustion. This law has been applied by Berthier to ascertain the quantity of heat liberated by any fuel when combining with oxygen.

The process of accomplishing this is as follows: The combustible, properly dried, is pounded into an impalpable powder. A given amount of this powder, say fifty grains, is intimately mixed with forty times its weight of litharge, and then placed in a good Hessian crucible. The whole is to be covered with a layer of litharge, to prevent the atmospheric air from penetrating into the mixture. The crucible is carefully placed in an air furnace or common stove. No particles of coal from the fire should be suffered to fall into it. In fifteen or twenty minutes, the crucible will be red-hot, and may be removed from the fire, or, what is still better, left until the litharge on the top is in complete fusion. After cooling the crucible, we find at the bottom a button of metallic lead. This must be weighed, for it is the true standard of the oxygen consumed by the fuel. One part by weight of carbon represents 2.66 parts of oxygen, which, taken from litharge, represents 34.56 parts of lead.]

To explain this more in particular: The equivalent or combining number of C is 6. To convert this C into CO^2 $\text{O}^2=16$ must be added CO^2 , therefore, is 22. For every equivalent of CO^2 as a whole, two atoms, or parts of O, must be abstracted from the litharge which is lead (103.7 parts, combining number) and oxygen (8 parts, combining number), or as protoxide of lead it is $103.7+8=111.7$ which is therefore the combining number of litharge (protoxide of lead). It is plain, therefore, that if one equivalent of lead (103.7) unites with one equivalent of O (or 8), two equivalents of O require two of lead (207.4). When the carbon is heated with the litharge, it unites with the O of the litharge in the proportion only of one C to two O, or as CO^2 ; the C is 6,

that of the $O^2(8 \times 2 =) 16$. Hence, every one part of CO^2 is equivalent to 207.4 lead left in the crucible for reasons just stated above. But every one part of CO^2 contains of its weight of CO^2 6 parts pure C, hence, every 207.4 pure lead is equivalent to 6 parts of pure C. Knowing, therefore, that what pure lead is found in the crucible owes its origin to abstraction of oxygen from the litharge ($103.7 + 8$) by the C of the CO^2 formed, it is easy to calculate the carbon by the lead, even now, without simplifying, and by the proportion: As 207.4 lead is to 6 carbon, so is lead found in crucible to carbon in the coal or alloy. But one part C is $\frac{1}{6}$ 207.4 = 34.56. Suppose therefore, one ounce of lead is left in the crucible, then the calculation would be: 103.7 Pb : 111.7 (protoxide Pb) :: 1 oz. : 1.077 (protoxide reduced by the assay). Therefore, 1.077 oz. of protoxide was reduced to make that 1 oz. of lead.

Now in 1.077 of protoxide of lead there was .077 of oxygen, that oxygen went to form CO^2 , but in forming CO^2 it did so by taking up only enough of C as would, with .077 of O, form CO^2 according to the laws of affinity, or in this proportion: As 160 : $22CO^2$:: .077O : .105 CO^2 . It consequently formed .105 of CO^2 . Now .105 CO^2 shows of pure C in the proportion of 22 : 6, thus we have $22CO^2$: 6C :: .105 CO^2 : .286C. Therefore, the one ounce of pure lead indicates that .286 of one ounce of carbon existed in the assayed fuel; if there had been originally one-half an ounce of assay, or .500 decimally, there was .500—.286=.214 carbon, or a little more than 42 per cent. carbon.

Having found the amount indicated by 1 oz. of pure lead, it would be easy therefrom to determine any amount by the following proportion:—

1 oz. (480 grs.) : .286 :: the weight of button : its carbon, or, as 34.56 parts of lead are equivalent to one part of carbon, as

Lead.	C.	Lead found.	C.
34.56	: 1	:: 480 grs.	: 13.88

[This amount of oxygen, carbon, or lead, will heat

78.15 parts of water from 32° to 212° ; so that every unit of lead represents $\frac{78.15}{34.56} = 2.261$ units of water, heated from 32° to 212° . One part of carbon combines with 2.66 oxygen to form carbonic acid; and one part of hydrogen combines with eight parts of oxygen. If, from the sum total of oxygen, we now subtract the amount of oxygen which the fuel contained, we shall find the amount needed for combustion; this latter is the measure of the power of heat of the fuel. For example, oak wood is composed of 0.4943 carbon, 0.0607 hydrogen, which takes $0.4943 \times 2.66 + 0.0607 \times 8 = 1.318 + 0.485 = 1.803$ oxygen: subtract the oxygen of the wood $= 0.445$ then $1.803 - 0.445 = 1.358$ oxygen is left. This is equal to 17.58 lead or 39.8 water, which by one part of oak wood can be heated from 32° to 212° . In this way the value of fuel, or the quantity of heat it liberates, may be very simply ascertained. But the iron manufacturer must pay particular attention also to the quality of heat, of which we shall speak hereafter. In accordance with this method, the following experiment has been made, The water is assumed to be heated from 32° to 212° Fahr.

1 pound of bituminous coal will heat 60 pounds of water.

1	"	pure carbon	"	78	"
1	"	charcoal	"	75	"
1	"	dry wood	"	36	"
1	"	air-dried wood	"	27	"
1	"	peat	"	25 to 30	"
1	"	alcohol	"	$67\frac{1}{2}$	"
1	"	oil, wax	"	90 to 95	"
1	"	ether	"	80	"
1	"	hydrogen	"	236	"

These substances naturally combine with various amounts of oxygen. Assuming oxygen to be one, and the water to be heated from 32° to 212° , then

1	pound of oxygen combining with hydrogen, will heat	$29\frac{1}{2}$ lbs.
1	" " " carbon,	$29\frac{1}{4}$ "
1	" " " alcohol,	28 "
1	" " " ether,	28 "]

Practical Remarks on the Analysis of Coals.—The four classes of fuels to which our attention has been directed, are, 1. *Charcoal*; 2. *Coke*; 3. *Bituminous Coal*, or *Raw Coal*; 4. *Anthracite*. There can be no doubt that a complete analysis of the coals used in the furnace, whether that furnace be the blast, or the puddling or reheating furnace, would be always important. But such an analysis requires much judgment and some skill, previously exercised in relation to the choice of specimens of the coal to be analyzed. A strictly chemical analysis of the carbon in coal may be very deceptive, and indeed very inaccurate, in a case where the metallurgist requires only the *heating value* of his coal, for in the chemical process by litharge, already described, or the oxide of copper process described in the appendix G, although extremely accurate, is subject to this error; it gives the amount of carbon, inclusive of that carbon which is so combined in the slate, or graphite, associated with all mineral coals, or it may give that carbon which is in such a condition that, *practically*, it is of no advantage to the furnace for heat. The only true practical value, therefore, of an analysis of coal is that wherein it gives us the *heating value* of that coal.

Practically speaking, this value may be arrived at with but a small amount of trouble. 1st. By heating a weighed amount, not less than 20 lbs., properly selected, in either a riveted sheet-iron box prepared for that purpose, with tubes of sheet iron leading therefrom, or in a large earthen retort. The volatile matter composed of hydro-carbons—bitumen, tar, &c.—will escape with ammoniacal gas and some sulphur. By using ordinary care, and surrounding the receiver with cold water or ice, these gases may be condensed, or may be passed into water, and the gaseous carburetted hydrogen, if any, allowed to escape. On the surface of the water will be the condensed oil, and the advantage gained by using water will be found in that the water will contain the sulphur, provided about one-fiftieth part, or about one fluid oz. of ordinary nitric acid has been previously added to two quarts of water, the amount

necessary to be used for distilling over from 20 lbs. The amount of sulphur, thus brought over, may be determined by collecting the precipitate resulting from the addition of a solution of chloride of barium to the separated water, *i. e.*, the water drawn off from the bottom of the glass receiver which holds the water and floating oil, or tar. This may be done by running a glass tube, bent syphon-shaped, down into the jar, through the oil, &c., to the bottom, and turning the jar over upon one side so as to cause the edge of the bottom of the jar to be lowest, and then drawing the water up into the syphon. A wire, with a little piece of muslin wrapped around its end and securely tied, dipped into water and then inserted far up the tube (which need not be more than $\frac{1}{2}$ in. diameter), with its other end extending beyond the lower end of the syphon, will enable the operator, by drawing the wire out, after the end of the syphon has been inserted in the receiver, to draw the water up the shorter arm of the syphon and cause the flow to be sufficient without the hazard attending the application of the mouth to the tube. The water should be filtered if it has been mixed with oils or dirt, and then evaporated to a small amount before the solution of chloride of barium is poured in. Filter the precipitate after allowing it to settle; wash it, dry, and weigh after heating it at a low red heat. Every 116.64 of the precipitate contains 16 of sulphur, or 13.7 per cent. of the weight of the precipitate is sulphur. Now while a larger proportion of sulphur remains in the coke by thus coking in close vessels than will remain in the coke if coked in ovens, in the large way, and while more sulphur remains in coke, even by the latter method than by coking in the open air, in heaps, and while it is true that not all the sulphur is obtained in the water or coke either by this method, but some remains in the oils and escapes in the gas, nevertheless, *relatively*, the practical amount of sulphur may always be determined, to a very useful degree, by this simple process, and by going no further. For if a metallurgist discovers that a coal which he has been using, is comparatively free from sul-

phur, and that by the process we have recommended it contains only 2 lbs. of sulphur to 1000 bituminous, which has been considered a fair average for the highly bituminous coal of South Wales (Rogers), then, by experiments, about one-half would be represented in the water of distillation in close vessels, and that being granted, it is plain that an increase, or decrease, upon that proportion would readily give the value of the fuel, in respect to sulphur, by the comparative amount of sulphur found in the water alone, and it is only the *comparative* value of coal which is needed, most usually.

What, therefore, are the practical lessons derived from analysis of coal?

In some places it requires 2400 lbs. charcoal to make one ton iron, of which 126 lbs., or 5.25 per cent., were composed of the following ingredients:—

Silex	.	.	.	.	.	64 lbs.
Alumina	.	.	.	.	.	26 "
Lime (Carb.)	.	.	.	.	.	10 "
Mag. (Carb.)	.	.	.	.	.	6 "
Potash (Carb.)	.	.	.	.	.	20 "
						<hr/>
						126 lbs.

Now these proportions will show the poor slag which would result was it not for the nearly 16 per cent. of carb. of potash and 8 per cent. carb. of lime, which readily make a flux with the remaining ingredients, but all depends upon the potash, so far as the fact of fluxing is concerned. Now we will look at the following analyses of other coals. In the same region, the ores being about the same, the assertion is, that about 4480 lbs. of coke are required to make a ton of best foundry iron. Of this there are 448 lbs., or ten per cent., ashes, of following composition:—

Silex	.	.	.	.	.	292 lbs.
Alumina	.	.	.	.	.	65 "
Mag. (Carb.)	.	.	.	.	.	32 "
Per. Ox. Iron	.	.	.	.	.	36 "
Lime (Carb.)	.	.	.	.	.	23 "
						<hr/>
						448 lbs.

Here are found only 5 per cent. lime to 65 per cent. silex, and no potash whatever. The latter fact is characteristic. We see, therefore, why the ashes of bituminous coal and coke will not flux in themselves. The above samples are rather poorer than usual, but they answer this purpose sufficiently well. The following is the analysis of an American bituminous coal, from Quin's Run, Clinton County, Pa., supposed to be "a superior article;" per cent. ashes, 6.80:—

Silex	76.00
Alumina	21.00
Peroxide Iron	2.60
Loss . . . . .	.40

100.00

(W. R. JOHNSON.)

Here then is no lime and much silex and alumina. In the anthracite the same lack of fluxing proportion exists, and the alumina seems to be in excess, as is seen in the following table:—

	SUGAR LOAF Co., HAZLE CREEK, PA.			Buck Mountain.	Salem Vein, Pottsville.
	No. 1.	No. 2.	No. 3.		
	Sp. gr. 1.591.	Sp. gr. 1.574.	Sp. gr. 1.55.	Sp. gr. 1.559.	Sp. gr. 1.569.
Per cent. ashes .	4.83	8.73	2.242	3.079	6.75
Color	light buff	reddish white	white	reddish buff	brick red
Silex (per cent.).	53.603	45.105	43.68	45.60	50.00
Alumina	36.687	37.000	39.34	42.75	38.90
Peroxide of iron .	5.590	13.000	8.22	9.43	8.00
Lime	2.857	1.380	5.76	1.41	2.10
Magnesia	1.076	2.430	3.00	.33	.90
Oxide manganese	0.186				

We see, therefore, that one characteristic of charcoal fuel is the large amount of potash in the ashes, and although we may probably use the specimen of charcoal above referred to, it gave, nevertheless, an unusually large amount of ashes. Hard wood-coal gives more than soft, the latter, as in pine wood, giving only 0.307 total waste in ashes (W. R. Johnson), and an average is a good representative per cent. for usual hard-wood charcoal.

But the next and more important characteristic of charcoal, is its freedom from sulphur. While charcoal seldom contains a trace, no other coals are entirely free. Thus the Quin's Run coal, represented above, had 0.1019 per cent. of sulphur, though considered a "superior coal." The ashes were nearly white, and this fact is important to remember, for the color of the ashes will frequently give a very good intimation of the amount of sulphur, as the sulphur, combining with the iron, will be in proportion to the iron which is found peroxidized by the heat after the escape of the sulphur. That per cent. (0.1019) would give a little more than 2 lbs. of sulphur to the ton. As the iron combines with sulphur in coal in the proportion of 46.7 to 53.3 in 100 parts, it is plain that there was 1.75 lb. of iron, or 3.75 lbs. of iron pyrites. So that the color of the coal ashes will aid much in determining a judgment as to the amount of sulphur in the coal, one-tenth of one per cent. being the representation of a quantity of iron giving a nearly white ash. In the table above we have the last mentioned fact illustrated, that the discoloration of the ashes will give an approximate test of the iron, as may be seen by noting the amount of ashes and then the amount of peroxide of iron proportioned to that amount, and it also gives, indirectly, a test, or good grounds for suspicion, as to the quantity of sulphur. While this is emphatically true as to the bituminous coal, it is also true, though in a modified degree, as applied to the anthracite. We have corroborated this by experiments upon a large number of coals, and, though there seems to be present considerable sulphur, even in perfectly white-ash coals, due to sulphuric acid and sulphur in other combinations than with iron, yet the rule has not many exceptions that, where the ash is red it indicates the presence of sulphuret of iron, as above stated, and in proportion to the depth of color of the ashes.

We see, therefore, just where the practical value of coal analysis is expected to show itself. 1st. In determining the heating value of the coal. 2d. In deciding

the nature of the ashes. 3d. In revealing the comparative amount of sulphur.

“Raw Coal,” or uncoked Bituminous Coal.—The benefit arising from the use of this coal in this state is now readily determined. As we have seen, bituminous coal and anthracite are only different conditions of the same fuel, modified by heat and long periods of natural distillation. In Wales, all the various conditions of transition, from highly bituminous coal to hard anthracite, are to be met with in comparatively a small district. In the United States the hardest anthracite occurs at the anthracite beds, near Fall River, Mass. The spec. grav. being about 1.84. In Pennsylvania the anthracites, as we have seen, gradually decrease in spec. grav. as we go west, and show great changes, even in the anthracite region, but westward the gravity decreases, and the bituminous element and gases increase, until the transition resolves itself into the decidedly and highly bituminous coals of the western part of Penn. All the difference in the coal, therefore, radically consists in, what might be pre-supposed, less volatile matter, less sulphur, and a denser physical condition. A true anthracite has so little volatile matter, hydro-carbons, etc., that no anthracite can be coked, and no carburetted hydrogen flame, that is, no yellow flame nor smoke can escape, and therefore it burns with the short blue flame of carbonic oxide. At the same time it has the same elements in its ashes, in about the same proportion. Now when coke is compared with raw fuel, in the furnace, there is, doubtless, more carbon, and more heating power in the cubic foot of raw coal than in the coke made from that cubic foot of raw coal, as we have seen in the foregoing tables. The volatile matter drawn off is so much waste of carbon, but (1) chemically, the sulphur in raw coal is generally three times larger in quantity than it is in the coke prepared carefully in open beds, from the same raw coal, and (2) mechanically, the coking and swelling of the bituminous coal sometimes occasions difficulty in the regular descent of the charges and the free passage of

the blast. These difficulties *may* be obviated; plainly, therefore, in that case raw coal is an economy.

It may be desirable to test the pig iron for sulphur where sulphur may be traced to no cause but the coal, and it may readily and easily be done thus: Take several specimens of the pig iron, cut them with a clean file, and put 30 or 40 grains into each of as many vials as there are specimens. Pour on a half fluidounce of H Cl upon each specimen, hydrogen gas will be evolved immediately, which will be more or less sulphurous in smell, according to the amount of sulphur in the iron. Now, having previously dipped several strips of bibulous white paper into a solution of ordinary sugar of lead (acetate of lead), half dried them, and held them 6 or 8 seconds over a strong solution of ammonia, pass these strips over, and within a quarter of an inch of the mouths of the vials, noticing the time it takes to darken the strip and the deepness of the stain. This stain is sulphide of lead, and the more sulphur is evolved with the hydrogen the more rapidly will the stain appear, and the deeper the brown or black sulphide will appear upon the strip. An extremely small amount of sulphur may thus be detected, and practice will soon enable one to judge very well indeed of the amount of sulphur in a specimen. (See Appendix H.)

In conclusion, greater care will have to be taken in the choice of coal, than has been exercised in many places, and more skill exhibited in the choice of material, where there is reason to suspect more than a usual amount of sulphur, for, as we have seen, p. 121, there are elements quite available whereby remedies may be applied, and we may sometimes adopt them readily when we only have learned that the difficulty exists. Although sulphur drives carbon out, as shown p. 121, it has been declared, in England, that an increase of the quantity of carbon, made a constant quantity in some of our furnace charges, will have a decided tendency in driving the sulphur out. (Rogers.) This may be so in theory, but practice does not seem to sustain the assertion. At Pittsburg, we were informed by an experienced master

(Benj. Crowther, Esq.) that he succeeded in largely correcting the evil influence of sulphur upon his iron, by using increased proportions of limestone, and accordingly we found that his slags effloresced in the roads where they were thrown, from the excessive amount of lime. An analysis, however, showed that his limestones were fossiliferous phosphate. This corroborates what has been said on the page referred to above, for phosphorus certainly has a tendency to expel sulphur from the iron.

PART II.

PRACTICAL METALLURGY OF IRON.

CHAPTER I.

ROASTING OF IRON ORE.

WHETHER an iron ore should be roasted, is a question which very seldom arises; at least this question seldom ought to arise. With the exception of the red impalpable oxide, the whole series of iron ores require roasting; even the specular iron ore, if it is very compact; but the best oxide, if too compact, works badly in the furnace. All other ores should be subjected to calcination. Some iron masters are in the habit of using the hydrates raw, but this should not be done where clay ores are smelted, or where the hydrates contain either chlorides, or phosphates. But in the latter case, the pig metal will be cold-short if there is too much phosphorus. Under all circumstances, however, it is best to roast the ores if we expect good metal and well-regulated furnace operations.

The object of roasting ores is to produce higher oxidation, and to expel injurious admixtures. In both cases, liberal access of atmospheric air is required; we should, therefore, so arrange our roasting operations, as to fulfil these conditions, from which it will appear that different ores require different treatment. To explain this more fully, we shall take a review of the various ores.

Magnetic Oxide of Iron.—This ore is very compact, heavy, and of an almost metallic appearance; to open the textures of the ore, to make it more porous, lighter,

and to oxidize it more highly, it should be roasted; sulphur is frequently combined with it. This ore melts into a slag by a cherry-red heat; we should, therefore, avoid a high heat, for a melted clinker is useless and injurious in the blast furnace.

Hydrated Oxide of Iron, Brown Oxide, Hematite, Bog Ore.—This whole class ought to be roasted, not for the purpose of oxidation, but in order to drive off the acids, and destroy sulphurets and phosphurets, for all the ores of this class contain more or less injurious matter. This ore will bear a high temperature in roasting, if there is no foreign matter mixed with it; but of this it is very seldom free.

Sulphurets of Iron.—These, of course, require roasting, if designed for the manufacture of iron; the manipulation is difficult, and requires more than usual attention and time.

Phosphurets of Iron, where they happen to be mixed with the oxides, should be roasted, if we may expect medium qualities of iron; but if the quality is no object, and cheapness the aim, then phosphurets, in their raw condition, will answer.

Arseniurets of Iron.—If iron ores contain arsenic, it is best to roast them; arsenic does not injure the metal; but if the top or shaft of the blast furnace works cool, there is sometimes danger of choking at the top, or of scaffolding at the lining above the boshes.

Chlorine contained in iron ore does no harm whatever, and may be considered beneficial in roasting.

Sulphates of Iron should be carefully roasted with liberal access of air. This will apply also to

Carbonates, which require careful treatment. In the furnace they melt before carbon has any influence upon them; and if there is any admixture of foreign matter, the carbonates are very apt to produce but a small quantity of white iron, with black cinder. The roasting of carbonates is difficult; the best means of roasting them are low heat, and, if possible, access of watery vapors, partly to carry off the heavy carbonic acid gas, and partly

to prevent a too high temperature; for, if the heat is too strong, the carbonate melts together with the oxide, and forms a black cinder.

It is evident that, as the qualities of these ores are different, they should receive different treatment; and the question which meets us is, what arrangement, in each particular case, will best enable us to arrive at the highest perfection. For roasting ores, there are three distinct modes of manipulation—ovens, piles, and rows. Each arrangement may be considered perfect for a particular kind of ore; but each is not equally applicable to all varieties of ore. We must modify our manipulations according to circumstances, in order to produce appropriate results.

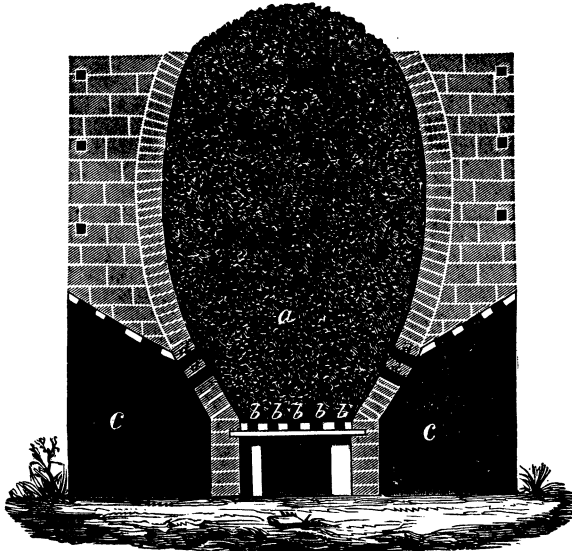
Under all circumstances the ore to be roasted should be broken into pieces, say two or three inches; if we neglect this, of course we cannot expect the best result, for it is obvious that large pieces will not receive heat and oxygen through their whole body so soon as smaller pieces; and as the object is volatilization or oxidation, no means should be neglected which will accomplish the end in view. The kind of fuel required is not of so much consequence as it is usually thought to be at charcoal furnaces. Wood and small charcoal (braise) are used; but where wood is scarce, stone coal, properly applied, will answer; coke, or anthracite is preferable. Bad, or sulphurous coal should be avoided, or at least coked before used. Turf or peat, or brown coal may be used, where they can be obtained upon advantageous terms.

Roasting of Iron Ore in Ovens or Furnaces.—There are many different forms of ovens, but all of them can be reduced to that of the blast furnace, or the limekiln. They are either perpetual, or work by charges.

These ovens are commonly from twelve to eighteen feet high, and contain from fifty to one hundred tons of ore at once. Fig. 39 represents such an oven for perpetual work: *a* is the shaft or circular hearth, where ore and fuel are thrown in; *b, b* are the grate bars, which can be removed to let down the roasted ore; *c, c* are side

arches, which permit access to the draft holes ; *d, d, d, d* are four arches, including the work arch. To start ope-

Fig. 39.



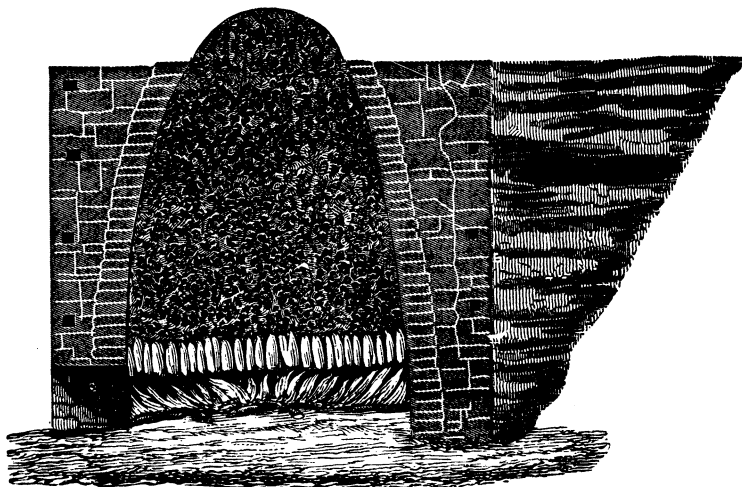
Section of a roast-oven.

rations in such an oven, the grate bars are covered with wood ; upon this either small charcoal, or stone coal, coke, peat, brown coal, or any fuel fit for the purpose, is placed ; then a layer of coal or ore alternately, until the oven is filled, after which the fire is kindled. When the lower portions of ore are sufficiently roasted and cool, they are taken out, and either carried to the furnace, or, in case the ore is not sufficiently roasted, returned to the top. The air holes *d, d, d, d* are designed to admit air when it is needed, and to enable us to observe the progress of the work. An oven of fifty tons capacity ought to yield thirty tons of well roasted ore in twenty-four hours ; but this depends very much on circumstances, and especially upon the quality of ore to be roasted. As the top of the ore sinks, it is replaced by fresh charges of coal and ore. This oven is well qualified to roast the hydrates, carburets, and other easily worked ores ; but

will not answer for carbonates, sulphurets, or even magnetic ore, for these ores are too soon melted.

In some parts of Europe another kind of oven is in use, which affords a better product than the perpetual oven, and may be employed with great advantage. This oven is represented by Fig. 40. Its interior is a cone, wide at the base, and narrow at the top. At the bottom

Fig. 40.



Section of an ore-roasting oven.

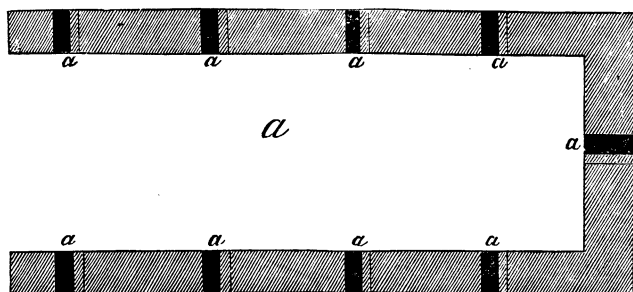
of this cone an arch of coarse pieces of iron ore is built, which supports the body of ore charged above it. This arch will admit enough fuel to keep up a lively fire. Where wood is plenty, it may be used in its green state, but any other fuel will answer quite as well. One great advantage which this arrangement has over the other (Fig. 39), is that it does not bring the fuel into contact with the ore; and the workmen are enabled to give just so much heat as they consider necessary. Such an oven, properly managed, may answer for any kind of ore provided it be sufficiently coarse to admit the draft of air needed for oxidation. Though this arrangement makes manipulating more expensive than the arrangement first presented, yet the qualitative properties of the product

which it furnishes—for there is no doubt that a good workman will deliver a more perfectly oxidized ore from this kiln than from the other—more than compensate for this expense.

An improvement upon this principle has been made in Sweden and Norway by erecting large circular ovens, like porcelain kilns, at the base of which, in furnaces built around, or in the centre of the oven, the fire is applied. Such an arrangement will work continuously, like that of Fig. 39, but is expensive both in the first outlay, and in the operation. Reverberatory furnaces have been tried for roasting ores, but with little success; the operation proved too expensive.

Roasting in Mounds.—Sulphurets and carbonates, which cannot bear a high heat, and require sometimes several fires, are best roasted in mounds. Mounds are formed on a level ground, and consist of three stone or brick walls: see Fig. 41. The area or hearth is open

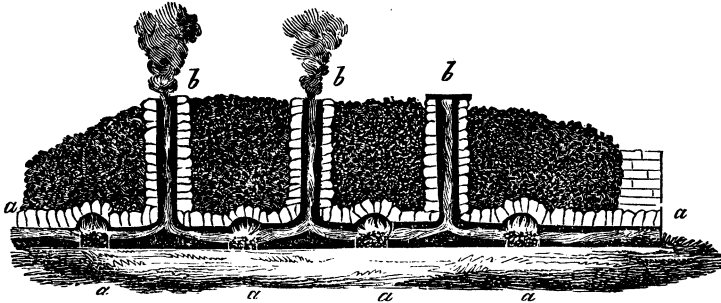
Fig. 41.



Ground plan of a roasting mound.

on one side, so as to admit the entrance of wheel-barrows or carts: the walls are about three feet high, and have at their bases fire chambers, where the fuel is applied. This is shown at *a, a, a*, Fig. 42. Through the piled ore are draft holes or chimneys, *b, b*, which regulate the draft; by these chimneys, the draft may be altogether stopped when the ore gets too hot. This kind of oven or mound is very useful for small ores, and those which cannot bear much heat.

Fig. 42.



Section of an ore-roasting mound.

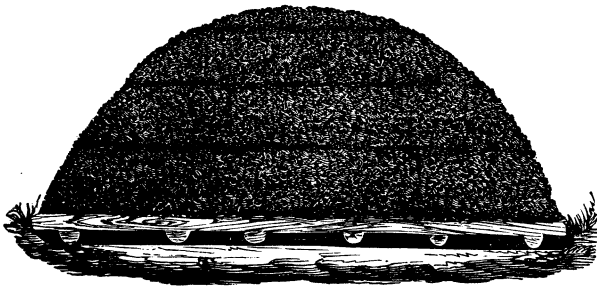
Roasting in the Open Air in Heaps.—This mode of calcining ore is undoubtedly the most available, and that generally practised. It affords by good management excellent results. To form a heap, or heaps, the ground must be levelled, and in many cases covered with beaten clay. The area of such a level depends entirely on the amount of ore to be roasted, and the time in which it is proposed to be done. It may be laid down as a rule, that the longer the fire remains in a pile, or the slower the roasting is carried on, the better will be the result. If the time is limited, rows of three feet high, from seven to eight feet wide at the base, and of convenient length, may be put up and fired. These rows may be finished in ten or twelve days; but though they answer well enough for hydrates, sulphurets, and all those ores which calcine easily, they do not answer for magnetic ore, or carbonates. For those ores which are roasted with difficulty, round or square piles of various dimensions are used; some of these piles have a capacity of from one hundred to two thousand tons. The amount of ore in fire should depend mainly on the stock on hand, and on the quality of the ore. Magnetic ore may be roasted in the course of six or eight weeks; argillaceous ores of the blue or gray kind, require at least three months; and the sparry carbonates can scarcely be roasted in one heat, frequently require different fires, and, after all, are but seldom sufficiently cal-

cined. In Styria, Carinthia, and other places where heavy sparry iron ore abounds, and where good iron must be delivered, the iron masters are compelled to have a stock of ore sufficient to supply the furnace for a number of years, and the complicated manipulations by which the sparry carbonates are oxidized, often require a period of from three to five years. The operation is there mainly conducted on the principle of oxidizing by the influence of the atmosphere; for that purpose the ores are broken into small fragments of the size of walnuts, then spread upon level plains, in a thin stratum of about two inches thick, and then exposed to the action of the sun and atmosphere; in dry weather the ores are sprinkled with water once or twice every day. Ores oxidized in this way are, of course, far superior to those oxidized by means of artificial heat. The method of roasting ore in the open air by artificial heat is as follows: Billets of wood are placed, like the bars of a grid-iron, upon a previously prepared level spot; sometimes they are laid parallel, and sometimes in a crosswise manner, so as to form a uniform flat bed. The crevices between the wood may be filled with chips of wood, charcoal, peat, or even stone coal, coke, or anthracite, so as to prevent the ore from falling between the other pieces of fuel, or, what is still worse, upon the ground. The ore, before it is put upon the fuel, should be broken into pieces of uniform size, of from three to four inches in diameter; the larger pieces to be used inside of the pile, the smaller ones for covering. When a foundation of fuel of about 8 inches high is prepared, ore may be piled upon it to the height of from eighteen inches to two feet; upon this ore is spread a layer of small charcoal, or of peat, coke or small anthracite coal, in a uniform thickness of two inches, or one inch of fuel to one foot of ore; then alternate beds of fuel and ore, until a sufficient height is reached. The pile, thus prepared, whether of an oblong, square, or round form, should be covered with small ore, and then should be set on fire either in the centre—for which purpose one or more holes or flues are left—or around the base. After the

fires are properly kindled, the piles may be covered with riddlings of ore or small coal. The combustion should proceed slowly, being somewhat suffocated, so that the whole mass may be uniformly penetrated with heat. Where the fire is too intense, it must be covered with small ore or coal dust, and where it is too imperfectly developed, holes should be pierced with an iron bar, that smoke and air may have vent.

In all cases of calcining in heaps, the arrangement and manipulation are almost the same, with hardly any other variations than those arising from the difference of ore and fuel. Fig. 43 represents the section of an ore

Fig. 43.



Section of an ore heap ready for firing.

pile, which is so plain as to need no description. In this plan the billets of wood are raised from the ground, which affords the advantage of enabling us to kindle the pile wherever we choose.

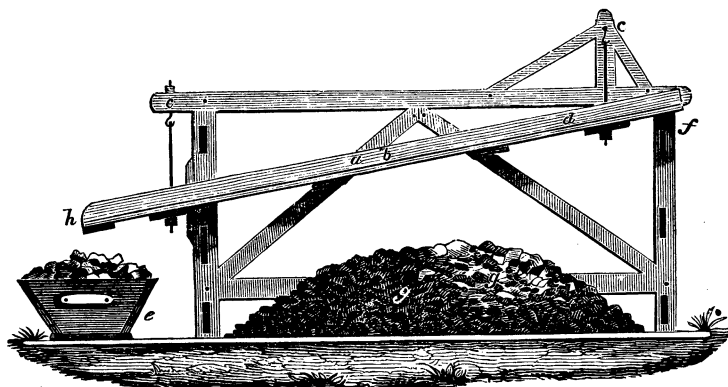
Cleaning of Roasted Ores.

Iron ores, after being roasted, are very apt to be mixed with foreign matter. Where great care is taken, as in some parts of Europe, this is separated. The usual method of accomplishing this, is as follows: A movable screen, made of a wooden frame, filled with iron bars from one-fourth to three-eighths of an inch in diameter, leaving one-fourth of an inch space between the bars, is put close to the ore pile. The dry ores are

thrown by means of shovels against the iron bars, when the fine ores and fine dust pass through the spaces between the bars of the screen, and the coarse ore rolls before the screen to the feet of the workman. Stones and coarse foreign matter may be separated by hand; the fine riddlings are thrown aside, or may be used for levelling the ore yard; mixed with lime, they make an excellent mortar.

A more convenient, though more complicated contrivance than the above, is the following. It is in general use: A strong wooden framework, made of oak scantling five inches thick, contains the screen *a*, Fig. 44, made in the usual way of round iron bars from one-

Fig. 44.



Machine for cleaning ore.

fourth to three-eighths of an inch in diameter, separated from each other by one-fourth of an inch space. It is a kind of flat box; the bottom *b* is formed of the iron rods. This box is suspended on wires, at four points *c*, which permit a swinging motion of the screen. If a shovelful of ore is thrown into the screen *a*, *b*, *d*, and a boy, standing by *f*, moves the screen back and forwards, the coarse ore will roll into the box or wheelbarrow *e*, and the riddlings or fine matter will accumulate in *g*, below the screen; *h* is a cross-piece fastened to the screen, which, by constantly striking against the frame,

occasions a more lively motion of the ore. This simple machine answers all that is required in screening, and is a useful fixture. The ores, when screened, should be cleaned by hand, that stones and lumps of other foreign matter may be removed.

The screenings or riddlings contain a large amount of ore, which is generally lost. Where this is valuable, and where the particles of the ore in the screenings are coarse, a great deal of it may be regained by washing the dust. Calcareous ores, or ores originally mixed with lime clay, and common earth, in fact all those screenings whose admixtures are sufficiently fine to be carried off by a current of water, may be advantageously washed, and the greater part of the ore thus recovered; but fine earthy ore dust cannot be saved in that way. The washing of this ore is generally effected in wooden troughs, where, by letting a continual stream of clear water flow upon the ore, and by repeatedly stirring the mass, the fine dust of lime or clay is loosened and carried off. This manipulation can be applied where the price of ore is sufficiently high to justify the expenses of the labor bestowed upon it.

Theory of Roasting Ores.

There is a variety of opinions on this subject, and iron masters by no means agree in relation to it. Some consider the manipulations mainly designed for the expulsion of sulphur, but if this were the case, all those ores free from sulphur would require no roasting at all. But all agree that the operation of roasting is necessary. Others regard the operation as exclusively a manipulation of oxidation, without reference to anything else; but we find that even the highest peroxides sometimes require roasting. We will confine ourselves at present to the most important part, or, the practical view, of the operation. The object of the manipulation of roasting or calcining may be considered mainly that of oxidation, for a heat sufficiently strong to oxidize ore, expels all other volatile matter; and the iron retains oxygen alone.

All matter generally found in iron ore, which is considered injurious to the metal, is more or less volatile, and expelled by a cherry-red heat ; for instance, sulphur, phosphorus, chlorine, arsenic, antimony, sulphuric acid, phosphoric acid, carbonic acid, &c. ; but copper and silver cannot be expelled, and ores which contain these metals must be rejected altogether. Therefore, by oxidizing the ore, we at once free it from all injurious ingredients, and on that account we should pay particular attention to the means by which metals, particularly iron, are oxidized.

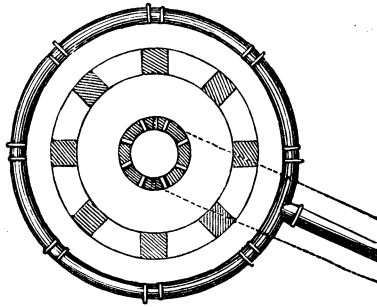
Iron corrodes, that is, oxidizes, very readily, but faster in a moist than in a dry atmosphere ; more rapidly by the presence of an acid than an alkali ; more quickly when divided into small particles, than in solid masses. If we apply these laws to the present case, we shall find that the breaking of the ore is advantageous ; that the presence of some water is very beneficial ; and that the burning of the fuel ought to be so far perfected as to form carbonic acid, but not to suffocate the fire, and thus form carbonic oxide. In applying this theory, we shall find that we ought to break the ore into lumps of uniform size ; roast the ore, when possible, by wood and charcoal, which generates steam and carbonic acid more readily than any other fuel ; and establish our ore yard on a moist ground, that a continual current of watery vapors may thus pass through the hot ore pile.] All things being equal the more slowly an ore is roasted the more thoroughly is it purified. Rapid roasting is almost certain to fuse, more or less evidently, the surface, and thus seal up all exit to the inclosed volatile matter, and render after-roasting useless. There is a vast amount of time lost in roasting after this glazing of the ore has occurred.

Further Remarks on Modern Practice.—As this subject is attracting additional attention among the more careful manufacturers in our own country, we present some of those methods, both of roasting ores and of coking, but especially of the former, adopted most satisfactorily on the continent of Europe. The following, with a brief

explanation, is from the recent work of Messrs. Petitgand and Ronna.

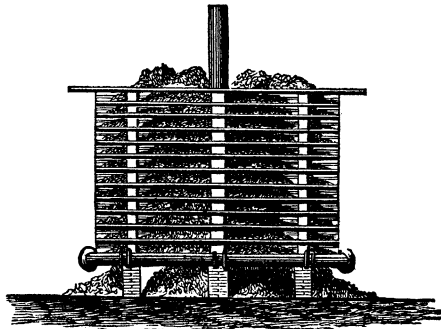
The ore is roasted in the air with wood, in Mariazell, Styria, on a plan which seems to give great satisfaction. We have no doubt but that the same, with scarcely any alteration, might serve with coal. It is represented as follows:—

Fig. 45.



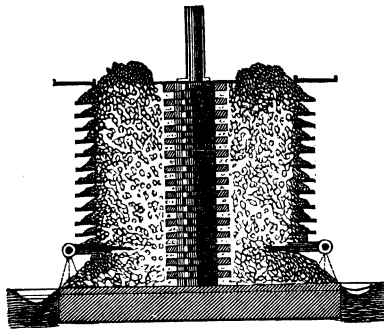
Upon eight short pillars of masonry, arranged in a circle as in the figure above, and themselves built upon a plate of iron or foundation is placed a circular plate, surrounded with perforated water pipe, in case of steaming sulphuret ores. A draft chamber leading to the centre is prepared as above indicated. This first circular plate projects inwards, as seen in Fig. 47. Above this plate eleven other plates are similarly placed as is seen in the same Figure.

Fig. 46.



Each plate is put upon a circle of short brick pillars or supports of height equal to the distance between the circular plates. At last the cap, or top iron circle, is placed and somewhat exceeds the others in diameter, as seen (Fig. 47). In the centre of all is a cylindrical chimney closed at the top with a plate and smaller pipe, as seen in the following cut :—

Fig. 47.

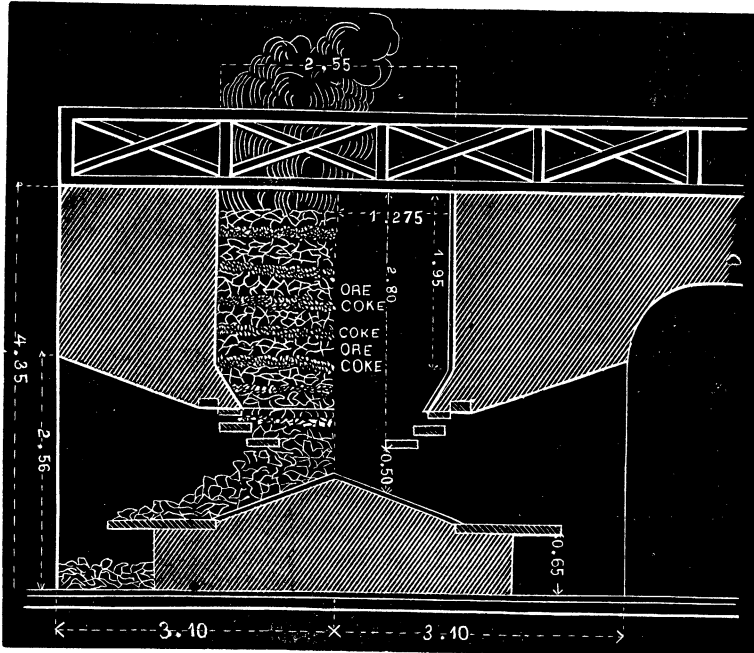


The chimney should be built with open perforations, as indicated with sufficient accuracy in the above drawings. This simple plan works to great satisfaction. The height and diameter must be suited to the wants of the manager; but when the oven is erected upon a circle of columns, the inner diameter of which is 9 feet 6 inches, and height from ground about 12 feet, which is a small size, the roasting efficiency may be put at 7000 lbs. of ore per day, yielding 5600 lbs. of roasted ore when the ore is pyritous carbonate of iron, the amount not being materially altered in other ores.

The following has been adopted at Siegen. It is cylindrical, or conical shaped, and is one of very satisfactory results, being larger and better adapted to the purposes of our own country, for roasting with either anthracite or coke. It is used at Siegen with coke, and the measurements are given in French metres of 39.37 inches to the metre, although the exact measure is entirely arbitrary, except in proportions, as every manager will be governed by his own necessities. The foot plates, or

hearth plates, should be higher than in the French estimate, which is only $25\frac{1}{2}$ inches (.65 metre), as, in loading the ore, sufficient height should be had for running the ore cart, or barrow under the plate and loading directly. The cut is sufficiently plain.

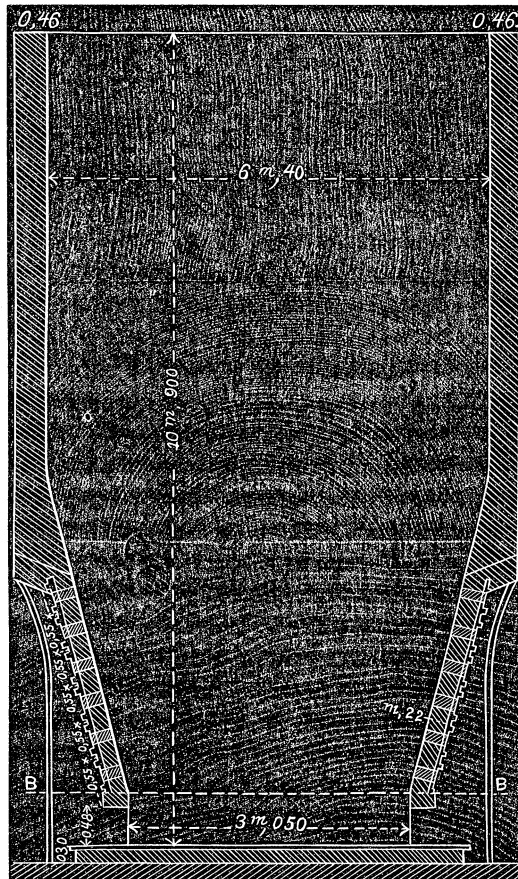
FIG. 48



A still larger and a very effective roasting furnace has lately been erected at the Clarence Works, at Middlesboro', on the Tees, for the purpose of roasting the Cleveland ores. Its size is such that it would suit any of our furnaces, and it is spoken of as producing more satisfactory results than ever obtained by any of the former ovens. All those recently constructed have arrangements to arrest the loss of heat, when the fire arrives at the top of the oven, by plates of thick iron drawn in at the top, but in a uniformly circular course. About 200 tons of cast iron a week can be made from the supplies of each of these ovens, and over 30 per cent. of saving of

fuel above that which can be accomplished upon the old methods. The section of the oven alone, without the general top plan which would be arranged according to surrounding circumstances, will be seen in the following figures. In this oven, as in the former, we think the hearth plate too low for all cases wherein loading directly with the barrow, or cart is advisable. In the accom-

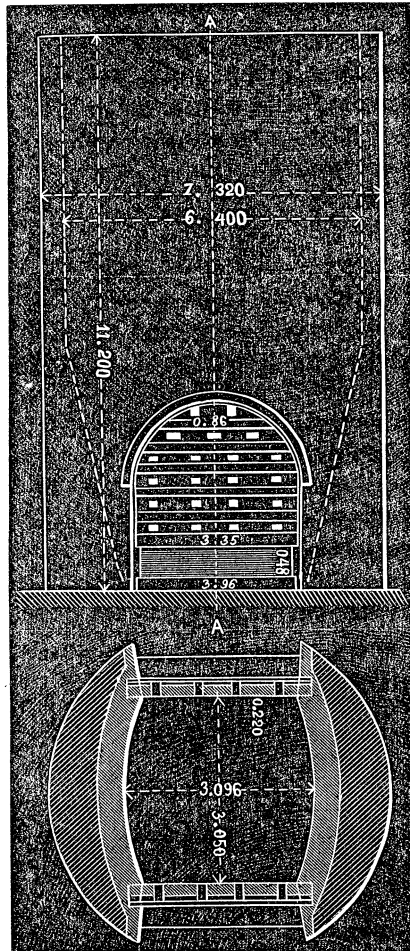
Fig. 49.



panying cut the height of the hearth plate is put at 0.30 above the ground, being 11 feet $\frac{8}{10}$, whereas it should be higher, as intimated above.

The above is the vertical section of the oven, as cut down through A A of the front elevation section given below, and is 35 feet 9 inches high, (10.900 metres) and 10 feet (3.050 metres) diameter at base. The following front section of elevation and plan of the hearth give additional measurements, and show the form of the

Fig. 50.



inside of the oven. In the breast of the oven the 0.86 is intended to be the measurement (1 foot 5 inches)

between centres of two air holes just over the figures. The figures 0.48 (1 foot 5 inches) is the height of the "draw mouth," or opening out of which the ore or coke is drawn. The plan of the hearth in Fig. 50 is taken at the height indicated by the line drawn through B B in the upper cut, and 0.220 metre, or 8 inches and six-tenths inch is the thickness of the breast wall. A very little study will, with the aid of the figures, explain the other parts.

CHAPTER II.

REVIVING, OR REDUCTION OF IRON. DIRECT PROCESS.

IF ores contained no foreign matter, or if they were purely peroxides, the reviving of iron from its ores might easily be effected. But such is not the case. The manufacture of iron is so highly complicated by the great mass of impurities in ores, that it has been found necessary to divide the general work into several distinct branches. This division affords the advantage of perfecting these branches of the manufacture, and consequently cheapening the product.

The reviving of iron is, at present, carried to so high a state of perfection that scarcely any improvement, so far as yield of iron is concerned, can be suggested. But the quality of the metal and economy of fuel, are attracting a large degree of attention.

In ancient times iron was extracted from the ore as malleable iron. This is called the *direct*, in contradistinction to the present method of producing cast iron and afterward malleable, which latter is called the *indirect* method. The ores used in the direct method were always the richest, and the fuel invariably charcoal. In the earliest method an open forge, and stones for anvils, were commonly used. The process was exceedingly tedious, and the iron produced extremely small com-

pared with the amount produced at the present time. The masses were produced without melting the ore, and they were called "blooms," from the Saxon, bloma, "a mass," "lump," or "metal." The same general methods are yet adopted in Asia and Africa.

Malleable Iron from Magnetic Sand.

The following description of a process of making malleable iron (1867) in India will explain itself. Much of the iron is made from black iron sand (proto-sesquioxide). A quantity of the sand is measured and divided into three parts, each weighing 26 lbs. Three bushel-baskets are filled and set aside. Two are emptied into the chimney, and one-third of the sand afterward. The fire is kindled and blown. When the fire subsides, one-half of the remaining charcoal and another third of sand are put in; when these have subsided the remainder of the charcoal and sand is added, and the fire is urged till six hours and a half have transpired from the beginning. The front of the furnace is then broken, and on removing the walls a mass of iron is found at the bottom, which is taken out with a large forceps and cut into two blocks, weighing each a little more than 12 lbs., so that the ore yields about $31\frac{1}{2}$ per cent. of metal. The iron so produced, although malleable at first, is extremely impure. The master used to take it from the workmen at 9s. $3\frac{1}{2}d.$ a hundred weight, and he gave great employment to the iron manufacturers, as he made his shot of this iron by hammering, for the fusion was never so complete as to allow it to be cast into moulds.

The operation for smelting ore is exactly the same as that used for the black sand, except in the cleaning of it. The ore is first reduced to powder with an iron bar, and then the earthy particles are washed away in a wooden trough, when it becomes exactly like the black sand, and is called by the same name, "adurn." The collecting of it is attended with less trouble than in collecting the black sand; but the difficulty and expense

of carriage to any considerable distance prevent it from being used in general.*

The Hindoos appear to have carried on the direct process from time immemorial, judging from the large masses of slag found in the various parts of India. Their furnace was generally not larger than a half barrel, and the toil incessant, whereby, with skins of goats and buffaloes, they kept up a blast. The same facts are true now which were known centuries ago. Alternate charges of charcoal and iron are introduced until the proper charge has been placed in the little clay furnace, and then the heat is increased, the slag removed from a hole, by a tool formed for the purpose, and, when the metal is reduced, the front is taken down and the metal hammered into a bloom. It is never melted into cast iron as in our blast furnaces.

A different form is used in the Himalayan Mountains, where the blast is sent into a hearth similar to that of a blacksmith's forge, and the blooms worked out in size of a few pounds at a time.

And yet in India, in 1844, malleable iron was cheaper than British iron at the time it was imported.

Variations upon that particular form and size indicated above, are used in Borneo, and Africa, and Madagascar, but the principle prevails in all alike, namely, the abstraction of oxygen from the purest kinds of ore, by means of the charcoal and without melting the ore, and the producing the reduced iron directly from the ore, into red, or white hot blooms of malleable iron.

Catalan Process.

The name is derived from Catalonia, in the north of Spain, where it probably was first introduced into the west of Europe.

A Catalan forge is a small affair compared with any present furnace. It consists essentially of a furnace hearth like a blacksmith's, a blowing machine, and a

* Engineering, 1867.

heavy hammer. If a blowing machine called a "trompe" is used, the forge must be erected where there is a stream, and fall of considerable height, 11 to 12 feet at least. The fuel is always charcoal, and the ores hematites and spathic ores. Sometimes these forges have been worked with blowing machines made of skins.

This process has been generally discontinued. The iron thus produced lacked in homogeneity, contained particles of steel, and, because of the imperfect extrusion of slag, was not perfectly malleable.

The process might still be used in places where other blowing machines and forges could not be easily erected. (See description at large under Wrought Iron.)

The Stückerfurnace.

The Stückerfurnace was the next improvement, being only a Catalan extended upwards in the form of a quadrangular or circular shaft.

The bloom was larger, but was often carbonized into cast iron, to the annoyance of the smelter.

Between the Catalan and the Stückerfurnace, metallurgists place the Blaseofen, or, as Percy calls it, Osmund furnace, continuing to be used to this day in Finland. The name is derived from the Saxon, signifying a bloom of the kind produced by the furnace. The peculiarity is, that the bog iron-ore (which contained a large per cent. of phosphorus) reduced by it furnished malleable iron much purer than when the same ore was reduced in the blast furnace of modern construction, which is used in the same region, and side by side with the Osmund furnace (the latter iron being cold-short and bad).

Not more than $1\frac{1}{2}$ ton of iron could be made weekly in one of these furnaces, and in working up the iron there was a loss of 33 to 50 per cent. of the iron.

The Stückerfurnace, or high bloomery furnace, may be considered the lowest development of the modern blast furnace. It was abandoned in many places because of the large amount of fuel it consumed. The furnace was in form that of two truncated cones, put together at

their bases, and about 12 to 16 feet high, with one tuyere, 14 inches above the hearth-stone, which latter sloped toward the drawing-hole, from which the metallic mass was drawn when reduced. The lump was divided by hammers and hatchets. It was an intermediate between cast iron and malleable iron; though soft, tough and malleable, it was less so than bar iron.

The condition favorable to the formation of cast iron, is prolonged contact of the reduced metal with carbon at a high temperature; and this is secured by increasing the proportion of charcoal relatively to the iron-producing materials. Hence, to produce malleable iron, the proportion of charcoal was relatively diminished. But one condition of working the *Stückofen* was the frequent removal of the slag, or the allowing it a free escape, so that the iron might not be protected from the blast. The blast oxydized the otherwise carbonized metal, and kept it free from carbon, or, what is equivalent, kept it malleable iron.

Clay's process was a type of many similar processes, and hence may be mentioned as a greatly improved method of obtaining malleable iron from the ore directly. The better kinds of red hematite were crushed to pieces of the size of walnuts, and then mixed with one-fifth their weight of charcoal, coke, coal slack, or other carbonaceous matter. These were then subjected to a bright red heat in a clay retort, until the ore was reduced to a metallic state, but not melted. The spongy iron was transmitted directly to a puddling furnace where it was balled, and then wrought into blooms under the tilt hammer and the blooms rolled. It did not succeed upon a scale large enough to meet the demands of the market.

Chenot's process was, in principle, the same as Clay's, modified by the furnace treatment; it was, as in the preceding case, "metallic sponge," or iron reduced from the rich ore to the spongy state, and then compressed while hot, rolled, and converted into merchantable iron.

The mechanical method of applying the deoxygenizing substance to the ore in Chenot's process was as follows: the purest ore was broken down into lumps of

less than two cubic inches. If in powder it was agglutinated by compression, and with addition of some reducing matters, as, *e. g.*, 3 per cent. resin. Thus prepared, it is mixed with an excess of charcoal. In practice an ore with 55 per cent. iron, is mixed with $1\frac{1}{2}$ to $1\frac{1}{2}$ its bulk charcoal, or by weight 190 parts charcoal to 1000 ore. This is charged into the furnace. The furnace is composed of vertical retorts, or chambers $6\frac{1}{2}$ feet long, $1\frac{1}{2}$ wide and 28 high. Below and at the bottom is a pit to receive the reduced iron, which is protected from the air as it falls out from the retorts, as it otherwise would take fire from rapid oxydization if exposed in this heated condition. Around these retorts are flues which convey the heat from the fires below to a chimney or stack above. The intense heat reduces the ore within the retorts without melting any of the ore, but by its direct deoxidization. The purity of the ore required for such direct reductions may be seen from the following analysis of the ore of Sommorostro, Biscay, Spain :—

Sesquioxide of iron	.	.	.	.	78.70
Oxide of manganese	.	.	.	.	0.65
Silica	.	.	.	.	10.01
Alumina	.	.	.	.	2.36
Lime	.	.	.	.	.06
Water	.	.	.	.	8.22
					<hr/>
					100.00

Also by the following from Companil, near Bilboa :—

Sesquioxide of iron	.	.	.	.	80.60
Protoxide	.	.	.	.	5.42
Oxide manganese	.	.	.	.	2.00
Silica	.	.	.	.	2.00
Alumina	.	.	.	.	.40
Lime	.	.	.	.	trace.
CO ²	.	.	.	.	3.39
Water	.	.	.	.	6.30
					<hr/>
					100.11

These samples, especially the latter, show the nature of the ore required to work successfully with this or any of the similar processes of direct extraction.

When the "sponge" is perfectly reduced it has a bright gray color, is easily sliced by a knife, and may be ignited by a match, when it burns till wholly oxydized. (Percy.)

The above is called the *indirect* method of heating, but there is a *direct* method of heating and reducing, with intermixture of carbon, by passing hot CO through the broken ore in a vertical retort. The retort, or vertical chamber, is connected with two carbonic oxide gas generators—charcoal being used to make the gas—and the retorts having cooling pits beneath to catch the reduced sponge, as in the previous method. For the indirect, or external method of heating, it is said, that, at Baracaldo, where 2000 tons annually were made in 1862, for the ton of finished merchant bar iron, the following proportion was required :—

1.15 of blooms, or No. 1 iron,
1.60 iron sponge,
2.56 ore free from powder,
3.00 of ore (analysis given above).

Yates' process is a modification of Chenot's process. As we have described the latter somewhat at large, we need only to add that the difference was in the furnace. Yates adopted vertical chambers much higher (35 feet) "the flame impinging upon each shaft about 10 feet from the bottom of it." The shafts were filled by means of hoppers at the top, and double air-tight doors at the bottom, so as to fill and extract without the admission of air. Nearer the top the gases were admitted into the shafts or vertical chambers.

We have particularly noticed these efforts at extraction of iron directly from the ore, because that, of late years, several similar processes have been adopted in our country with more or less success, and with more or less impression of the novelty of the principle as applied. We shall now present some American processes, with their modifications upon those which have preceded.

Perhaps the process now adopted at Clifton Works, N. Y., is, in its mechanical method, an improvement

upon any of the processes above cited. In these works the iron is made by the direct process, and the steel, as we shall see hereafter, is only subsidiary. The following description we have received from a former pupil, now engaged in the enterprise, and it explains the process sufficiently and accurately :—

Clifton is right in the woods, twenty-five miles from De Kalb junction, on the Rome, Watertown, and Ogdensburg Railroad, N. Y., with which it is connected by a wooden railway. There are immense deposits of exceedingly rich and pure magnetic ore here, and to this fact is owing the settlement of the place. A large portion of the ore is almost perfectly pure and free from sulphur, and is very compact, so that it is thought that it will answer better than the Cheever ore for lining furnaces. It has not yet got into the market, but probably will next summer (1869).

The steel works are located very near the mine, and on a lower level, so that the ore is run into the upper part of the building on cars, and passes down through the crusher and the rolls, falling on a platform above the furnaces ready for charging.

The process employed is the patent of Dr. George Hand Smith, of Rochester, and is as follows: The ore being crushed to about one-eighth inch size, is mixed with about half its bulk of fine charcoal, and charged two tons at a time into a reverberatory furnace of the following description, namely: Imagine a vertical section of a single puddling furnace modified thus, the grate being, say, upon your left hand; the bridge is made wide enough for the introduction along the length of the bridge of a common gas-house retort, into which flows petroleum or coal tar, which furnishes carburetted hydrogen. There are two or more hoppers on the top of the furnace to receive the broken ore, and several doors on the side for levelling the charges. At the stack end there is a flue dropping down and running directly back under the floor of the furnace, and dropping again vertically into a chamber communicating with the main chimney. The hearth is 12 feet long by 5 feet wide,

and the ore, when prepared, is raked out from the side doors into barrows. The volatilized petroleum passes out through holes in the top of the retort, and the carburetted hydrogen aids directly in reducing the ore. In about five hours the ore has been deoxidized and carbonized, so that the resulting "sponge" is really steel.

The sponge is then put into a common puddling furnace, intended for soft coal, and balled and hammered into a steel bloom; but as wood is the only fuel, they have been compelled to use it instead of coal. A puddling furnace adapted for wood has just been finished and trial of the sponge has been made, but so far without success. The failure may be owing to the open nature of the wood fire, which admits so much air as to burn all the carbon out of the sponge; we say *all*, for owing to the porous character of the sponge, it probably passes through to the condition of iron so rapidly as to make it difficult to stop at the exact time, when, the carbon being exhausted, the iron itself is attacked, and the whole is reduced to a cindery mass. Some members of the company seem to be somewhat discouraged, but we are confident that nothing but practice and skill are needed to make the operators successful. Perhaps the novelty is to be found in the form of the furnace and in the use of petroleum. The principle of reduction is the same as in the preceding process, the method of applying the carbon being different.

At any rate, the iron made by this process is excellent, and proper machines and appropriate skill may succeed in the economical reduction of the metal from those rich ores and in this method. It is only a question of economy, and not one of possibility, so far as iron reduction is concerned, and we have no doubt, could some method of saturating the sponge with the proper quantity of petroleum be adopted, that the necessary amount of carbon could be seized upon to make steel, or at least "steely iron."

In 1825 a patent was granted to Charles Macintosh, for the use of carburetted hydrogen in making steel, but it was by suspending bars of iron under great heat in

chambers permeated by this gas. It did not succeed. (Mushet.)

This process is, therefore, an improvement in the application of carburetted hydrogen upon the ore and not upon the iron.

Champlain Catalan Process.—The nature of the Catalan furnace is described fully under the head of Wrought Iron. This process is an adaptation of some modern improvements. In the United States the most interesting groups of furnaces are found near Lake Champlain, among the rich magnetic ore beds of Essex and Clinton Counties. There are about 30 Catalan forges and 136 fires.* Other groups are in northwestern New York, and in the regions of Buffalo and New York city. In these forges the hot blast is used, being heated over the fire, in the stack, in three arched pipes. The cinder goes to the bottom of the fire and is occasionally run off, while the iron forms a "loop" on the hearth of the furnace, and is dug up every three hours and shingled under a hammer. In reheated iron, one gross ton per fire in 24 hours, is good work, and about 300 bushels of charcoal, one-half hard and one-half soft, are consumed to the ton, with about $1\frac{1}{2}$ lb. pressure to the blast, with a temperature of about 550° Fah. Both water-power and steam engines are used. When water is used the stack takes all the products of combustion, but when steam, those products pass under the boilers. The commonest form of hammer is that of the wooden helve, with a cast-iron head, weighing 1500 to 2500 lbs. The Rogers hammer weighs about 5 tons. The ores, except when very rich, are roasted in kilns open in front and top, and then stamped and sifted. About 250 tons are piled on about 15 cords of wood, and burned down in about 24 hours. Some purest ores may be stamped without roasting.

The Ellershausen Process.—This is a process so nearly allied to the direct process that it may be noticed here. It is not entirely direct but largely so. The inventor

* Iron and Steel Assoc. Bulletin, July 24, 1867.

is Francis Ellershausen, who, it is said, presented his invention in September, 1868, to Messrs. Shoenberger, Blair & Co., of Pittsburg, who have carried the invention into successful operation. The process consists in "the mixing of solid oxides into and among fluid cast iron, or of fluid oxides with solid cast iron, the oxides being granulated or minutely subdivided, in such a manner and in such quantity as to produce a solid conglomerate of the two substances, oxide and cast iron, and also in effecting this mixture and producing the resulting pig bloom or pig scrap, without the application of other heat than that of the fused cast iron or oxide, as the case may be, thus dispensing with the use of a furnace for any part of the process of mixing after the melting of the cast iron or oxide, which ever of them is used in a fused condition.

"The material thus produced may be used in like manner as any wrought iron of similar shape, so that when raised to a welding heat, the pig bloom, manufactured as hereinbefore described, may be pressed, squeezed, hammered, rolled, or worked in any of the methods employed in the treatment of wrought iron, and with like results, excepting that the article of wrought iron produced by our process is superior in quality to that obtained in the ordinary way.

"The following description gives a sufficiently exact idea of the details of the process:—

"On the casting floor of the smelting furnace, a cast-iron turn-table about 18 feet in diameter, is revolved on rollers by a small steam engine. Upon the outside edge of the table stands a row of cast-iron partitions, forming boxes, say 24 inches wide and 10 inches high, open at the top. Just above the circle of boxes stands a stationary, wide-mouthed spout, terminating in the tap-hole of the furnace. When the furnace is tapped, the liquid iron runs down this spout and falls out of it in a thin stream into the boxes as they slowly revolve under it, depositing in each a film of iron, say one-eighth of an inch thick. But before the fall of melted iron reaches the boxes it is intercepted, or rather crossed at

right angles, by a thin fall of pulverized iron ore, which runs out of a wide spout from a reservoir above. These two streams or falls are of about equal volume, say one-quarter of an inch deep and twenty-four inches wide.

"The thin layers of iron and ore at once chill and solidify, so that by taking out the outer partition of the boxes (which form the rim of the turn-table) they may be removed in cakes of the size of the boxes, and weighing about one hundred pounds each. These cakes or blooms are put into a reverberatory puddling or heating furnace, and raised to a bright yellow heat. They will not melt at this heat, but become softened so as to be easily broken up with a bar. The four blooms are formed, in the furnace, by the 'rabble' of the workmen, as in ordinary balling operations, into balls. The balls are brought out, one after another, squeezed in the ordinary 'squeezers' to expel the cinder and superfluous ore, and then rolled into wrought-iron bars, which are now ready for market, or for further reduction into smaller finished forms."

Much is claimed for the process, in the way of cheapness, and also in respect to the range of ores which may be used. As to the former advantage, it may be said, that as the process only supersedes the puddling and part of the casting, the proper course, in determining the economy, is to estimate the amount of ore reduced by the direct method. This will be added to the saving over and above that gained by the rendering the puddling unnecessary. The saving thus will be understood only by the yield after a certain number of months. As to the second claim, in respect to range of ores, and the purity of metal as derived even from impure ores, which has been supposed to be a characteristic of the invention by one writer,* we can only say, that up to the present time, it is contrary to all practical experience whatever. The only virtue in the ore is found in the oxygen of the ore, which decarburizes the cast iron, and perhaps, in some degree, oxidizes a little sulphide and phosphorus, and, under high heat, changes silica into silicon, which

* *Pittsburg Gazette*, January 26, 1869.

results would have a tendency to improve the iron. But if the ore contain phosphorus, or sulphur, or arsenic, the iron, under a high degree of heat, would certainly absorb a quantity more or less, and therefore we imagine that the success, so far as the excellence of the iron is concerned, must depend upon the purity of the ore, and the excellence of the after reheating process.

The method is certainly in advance of former methods and processes, and is, in the philosophy of the process, correct, and only awaits mechanical skill and judgment to make it a successful substitute for puddling, in the quality of the iron, if not in economy. (Appendix I.)

Another method of applying the same general principle has been adopted in Schuylkill County, Pa., at Ringgold, where the ore, reduced almost to a powder, is caused to fall upon a series of shelves, while the carburetted flame passes over the descending ore as it is raked off from shelf to shelf, until it reaches the hottest part of the reducing chamber, and becomes massive enough for balling and blooming into wrought iron "loops," after which it is ready for the hammer or squeezer.

In all the above processes, one and the same principle is apparent, namely, the deoxygenation of the oxidized ore, by means of carbon, under its various forms and from various sources, whether found in charcoal, carburetted gases, or cast iron. The only practical difficulty is in obtaining quantity sufficient to cope with the exceeding yield of the blast furnace, and the ordinary process of the puddling furnace, in the same time and under the same expenses; but, so long as these conditions are not reached, it is in vain to attempt any such direct process, unless, by some means, a far purer iron can be made, which will command a so much higher price in the market, that it will allow of less iron being made in the same time, and at greater expense, than by the indirect process, which we are about to describe.

It will be noticed that in all the above processes, as *Direct*, in contradistinction to the *Indirect* process, the iron is reduced from the ore without melting the iron.

No doubt the first actual melting of the iron was accidental, and, as the result of increasing the height of the furnace, and of crowding in more coal and ore, with the object of gaining larger results. The long continuance of the ore in contact with the carbon, under great heat, caused the large absorption of carbon into the reduced iron, and thus the ore passed through various stages in the same heat, that is, it passed from ore to deoxygenized ore, or wrought iron, and then absorbing a little carbon, it became steel, then, absorbing more, it became our present cast iron, at which state it was fusible under less heat than at any previous stage, and then being allowed to flow it was tapped off. Many attempts have been made to arrest the deoxygenation at the right points to yield wrought iron and steel of various grades, according to the wish of the operator. We have now spoken of the practice and principles involved in the direct process, and shall pass on to the indirect.

CHAPTER III.

THE INDIRECT EXTRACTION OF IRON, AS CAST IRON, FROM THE ORES.

WHEN the furnace is in blast, the ore, the fluxes, and the coal are continually thrown in at the top of the furnace—the slag and the molten metal is continually coming down into the lowest part of the furnace—the slag floating upon the metal is drawn off continually from a higher aperture, and the metal through a lower. Thus there is a continuous descending of materials, and a continuous ascending of atmospheric air undergoing changes, until it either escapes into the surrounding atmosphere, or is conducted away into other parts of the furnace.

The oxygen of the air from the tuyeres, as it reaches the incandescent fuel, is more or less charged with car-

bonic acid, which immediately becomes carbonic oxide. If, therefore, there were no oxidized substances capable of reduction by carbonic oxide, and no volatile substances, the gaseous current would undergo no change, and, the gases escaping at the top would be chiefly nitrogen and carbonic oxide.

But this is not the case. Oxide of iron is reducible by carbonic oxide; limestone is separable into lime, and carbonic acid and certain other volatile substances proceed from the coal and other materials introduced. The oxide of iron in its descent is reduced partly by the carbon and partly by the carbonic oxides. But as the iron descends it is mixed with foreign ingredients, as silica, alumina, &c., and it is necessary that these ingredients be removed, and this must be done by fluxes, with which the foreign ingredients more or less combine, and are thus carried off as slag. Lime is found to answer well as a general flux. But, moreover, silica in large proportion from the coal and ores, and perhaps from the limestone in small degree, is present, and if there is not enough flux, of earthy character, chemically to combine, as a base, with the silica or silicic acid, then silicate of protoxide of iron is formed and carried off to a great loss. Now lime prevents this, or reduces the silicate after being formed, by decomposing and replacing the protoxide of iron. When there is a too large proportion of iron yielding material, or a heavy burden, it *does* happen and is tolerated. This involves a subject to be treated upon hereafter. The slag may also play an important part in protecting the surface of the iron, and preventing the decarburization due to the blast. (Percy.)

[We shall confine our attention, at present, to crude, or pig metal, and the apparatus employed for its manufacture.

Pig metal,* or cast iron, is a mixture of different metals, metalloids,† carbon, phosphorus, sulphur, &c., and

* The term "*pig*" is used to designate those short bars of cast iron, in the casting house, which branch off right and left from the main gutter-casting in the sand, called the "*sow*."

† Metalloid, having the form of metal, but not metal.

oxides; in which iron and carbon are the preponderating elements. The amount of carbon and other matter varies greatly in different kinds of iron, and the quality and quantity of these admixtures determine the value of the metal. The proportions of carbon in cast iron of all grades, and in steel, steely iron, &c., we have treated under the physical and chemical effects of alloys and admixtures of various substances in iron. Pig metal differs from bar iron chiefly in this respect, that it contains a large amount of carbon, and that it melts at a lower temperature. The making of pig metal is the first process in the manufacture of iron in the indirect method. Pig metal varies in quality according to the admixtures of foreign matter in the ore, and according to the mode of manufacturing it. Three very general classes of pig metal, ranging with the color of its fracture, may be specified. The first is of a dark gray or black color; it is generally sufficiently soft to receive impressions when struck with a hammer. It is not very strong; is easily broken; and shows, when fractured, shining crystalline pieces of graphitic carbon; it is coarse grained. This kind of pig metal will melt at a lower temperature than any other; and sometimes deposits, on cooling, graphite, in shining, mica-like leaves or crystalline structure. It contains a large amount of carbon, which results from much carbon in the blast furnace. If remelted in the air furnace, or in the cupola, it resolves into an excellent cast iron, which belongs to the next class. The second class is light gray metal. It is tougher and stronger than the first, as well as closer and finer in grain. It forms a good foundry metal; castings from it are strong and smooth. The third class is white metal, of two distinct kinds. One is the result of too much ore in the furnace, or of too heavy burden; or, if the charge is the same, it may be the result of lack of blast, bad coal, wet weather, inattention of the keeper; or of ores containing manganese. The other kind is generally silvery white, sufficiently hard to scratch glass; short, that is, easily broken; does not receive any impressions from the hammer, of a crystalline

fracture often very beautiful. A sudden change of temperature will sometimes break it. When struck, it emits a sound like that of a bell. The best metal for the forge is a cast between number two and number three, called mottled iron. It is white, marked with gray spots of graphitic iron.

The classification just given may be applied to anthracite and coke iron as well as to charcoal iron. We should add, that iron of the third class made by coke or anthracite is a poor article, and indeed, under all circumstances, furnishes inferior bar iron, the charcoal iron being generally superior to the anthracite or coke iron. Nearly every kind of pig metal, but especially the charcoal iron, alters its color, if suddenly cooled in a stream of cold water, or by sudden contact with cold surface, and it is then said to be "*chilled iron*." When hot, or when in a half-melted condition, the gray casts assume a whitish color. The cause of this behavior has been explained. This change of color is not the result of a loss of carbon, for such iron contains as much carbon as the gray iron from which it is derived. As a general rule, the color of the metal does not depend upon the amount of carbon it contains, for we sometimes find as much carbon in white as in gray pig metal.

We shall now proceed to describe the various modes of obtaining pig metal, or cast iron.

As we have seen in the former part of this work, if we mix finely powdered pure oxide of iron with dry charcoal powder, place the mixture in a Hessian crucible, and then expose the crucible to the melting heat of iron in an air furnace, we obtain a quantity of gray cast iron. If the ore contains, besides iron, any foreign matter, as silex, clay, magnesia, and lime, substances very refractory, the result of our manipulation is seriously impaired, for the revived iron, retained by the foreign matter, cannot follow its gravitating tendency. If the foreign matter is clay, or silex, the ore is partly reduced, forms protoxide, and combines with the clay and silex, from which it can scarcely be separated.

To prevent this combination, we must have recourse to alkalies of a stronger affinity than that of the protoxide of iron, such as lime, magnesia, potash, and soda, which combining with the clay and silex liberate the iron. These are the simple elements of the theory of the blast furnace.

We shall now proceed to enumerate the various forms of furnaces formerly used, and of those at present supposed to be the best types for the purposes of reducing ores in the formation of cast iron.

Before we present the first type of an indirect, or true blast furnace, we will speak of the transition furnace, which might be used for either process, and may, by the methods already intimated, have led, by a first step, to the modern practice. This furnace is seen in the Stück, or Wulf's Oven.

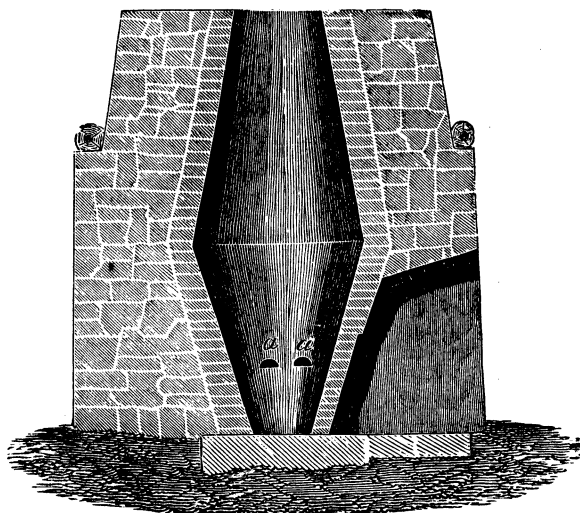
Stück, or Wulf's Oven—Salamander Furnace.*

This kind of furnace is at present very little in use. A few are still in operation in Hungary and Spain. At one time they were very common in Europe. The iron produced in the stück oven has always been of a superior kind, favorable for the manufacture of steel; but the manipulation which this oven requires is so expensive, that it has been superseded by the furnace next described. Fig. 51 shows a cross-section of a stück oven; its inside has the form of a double crucible. This furnace is generally from ten to sixteen feet high; twenty-four inches wide at the bottom and top; and measures at its widest part about five feet. There are generally two tuyeres [*twè-er*, allied to *tuyau*, a pipe], *a*, *a*; and at least two bellows and nozzles, both on the same side. The breast *b* is open; but, during the smelting operation, it is shut by bricks; this opening is generally two

* "*Salamander* is the term now given to the mass of half pure iron, which results when the molten mass of a furnace chills before it can be regularly tapped off into pigs. It is difficult to melt, and is sometimes largely malleable iron. The present may have originated from the earlier use of the word as applied to this furnace.

feet square. The furnace must be heated before the breast is closed; after which, charcoal and ore are thrown in. The blast is then turned into the furnace. As soon as the ore passes the tuyere, iron is deposited at the bottom of the hearth; when the cinder rises to the tuyere, a portion is suffered to escape through a hole in the dam *b*. The tuyeres are generally kept low,

Fig. 51.



Wulf's oven.

upon the surface of the melted iron, which thus becomes whitened. As the iron rises, the tuyeres are raised. In about twenty-four hours, one ton of iron is deposited at the bottom of the furnace. This may be ascertained by the ore put in the furnace. If a quantity of ore is charged sufficient to make the necessary amount of iron for one cast, a few dead or coal charges may then be thrown in. The blast is then stopped; the breast wall removed; and the iron, which is in a solid mass, in the form of a salamander, or *stück-wulf*, as the Germans call it, is lifted loose from the bottom by crowbars, taken by a pair of strong tongs, which are fastened on chains, suspended on a swing crane, and then removed to an anvil, where it is flattened by a tilt hammer into four inch-thick slabs,

cut into blooms,* and finally stretched into bar iron by smaller hammers. Meanwhile, the furnace is charged anew with ore and coal, and the same process is renewed.

By this method, good iron, as well as steel, may be furnished. In fact, the salamander consists of a mixture of iron and steel; of the latter, skilful workmen may save a considerable amount. The blooms are a mixture of fibrous iron, steel, and cast iron. The latter flows into the bottom of the forge fire, in which the blooms are reheated, and is then converted into bar iron by the same method adopted to convert common pig iron. If the steel is not sufficiently separated, it is worked along with the iron. This would be a very desirable process, on account of the good quality of iron which it furnishes, if the loss of ore and waste of fuel it occasions were compensated by the price of bar iron. Poor ores, coke, or anthracite coal, cannot be employed in this process. Charcoal made from hard wood, and the rich magnetic, specular, and sparry ores are almost exclusively used.

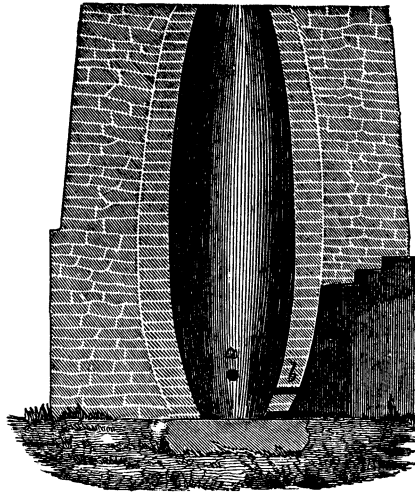
Blue Oven—Cast Oven.

The furnaces of this construction are an approximation towards the blast furnace of the present time. Fig. 52 represents the blue oven of the Germans. Its height is from twenty to twenty-five feet. The form of the interior resembles that of the modern blast furnace; *a* is the tuyere; the breast *b* is closed with fire brick, or fire-proof stones. The bottom slopes towards the breast. This furnace is kept in continuous blast for three, six, or more months, when the hearth widens so much that further work is not deemed profitable. When the furnace is heated to a sufficient degree, the breast is entirely closed, with the exception of a hole at the bottom to let out the iron, and of a hole six or eight inches above the first, through which the scoriæ flow out.

* Anglo-Saxon, blōma, *a mass or lump*; it is technically the crude iron from the furnace after having been hammered in the first rough manner.

It is filled to the top with coal and iron, the supply of which is renewed as the charges sink. The tuyeres

Fig. 52.



Blue oven.

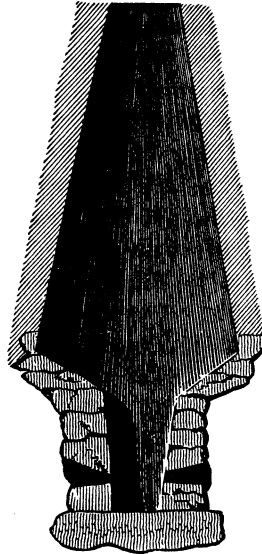
are seldom raised more than from ten to 14 inches above the bottom; should iron and cinder rise to the tuyeres, they may be let out. The arrangement, generally, is such that both may be let out through the tapping hole for the iron. But if the metal is designed for the making of steel, iron and cinder are tapped off together; in other cases, each is tapped separately. This furnace is in common use on the Continent of Europe. It is well adapted for the manufacture of steel, and yields an excellent forge iron; but it requires rich ores, and an abundance of charcoal. Its management is simple; it may be constructed at little expense; and where rich ores and cheap charcoal are available, may be profitably used in this country. The blue oven is generally used where sparry carbonates abound; and from the steel metal which it furnishes, German or shear steel is manufactured.

Later Forms of Furnaces.

The first improvement was that of the salamander furnace; the second, that of the blue, or cast furnace. We shall illustrate the gradual improvement in the following notice of the many various forms of blast furnaces at present in use. It will be sufficient to describe simply the interior of these furnaces, for their outward forms present but little variation.

a, Fig. 53, represents the interior of a charcoal furnace in common use in the Hartz Mountains. This furnace is a peculiar one, on account of its very heavy masonry; the crucible *c* is very high and narrow; the boshes* *b* are exceedingly flat; the interior will receive a large body of coal and ore; the throat is often from four to five feet wide, and sometimes square. Coal and ore are expensive in these regions, and this furnace is constructed as well for the purpose of saving fuel, as for producing a good quality of metal. The ores in use are the red, brown, and yellow varieties of the sparry carbonates frequently mixed with varieties of brown hematites, all of which are very refractory. The furnace is generally blown with one tuyere made of copper. Hot blast, as far as we are aware, was formerly only applied to two furnaces in that region. This furnace is celebrated on account of the very fine, strong bar iron, and the white plate iron, from which steel is manufactured, which it produces. It is managed like any other furnace; the cinders flow (in conse-

Fig. 53



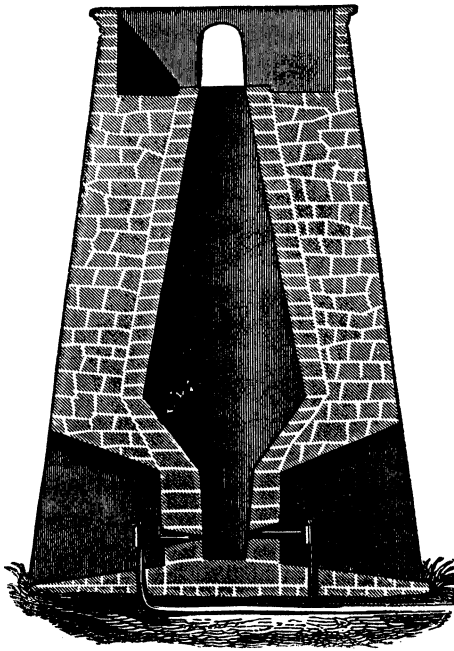
Blast furnace, Hartz Mountains, Germany.

* German, *Boshung*, a *slope*, that part of the stack of a furnace which slopes from the widest part down towards the hearth.

quence of their small specific gravity, and by the pressure of the blast) over the damstone, which is generally square, and lined with cast-iron plates. The metal is cast, by means of cool moulds made of cast iron, into plates ten or twelve inches wide, two inches thick, and from five to six feet in length.

Fig. 54 represents a blast furnace at Melapane, Silesia. It is twenty-seven feet high; it is blown with two

Fig. 54.



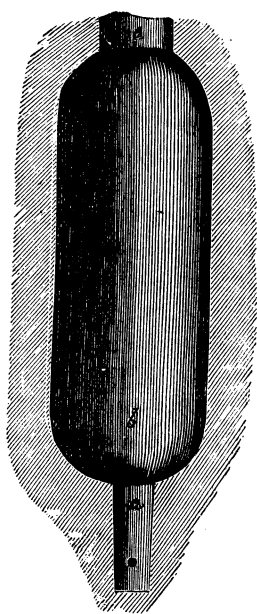
Blast furnace in Silesia.

tuyeres and hot blast. The blast is heated at the top. The crucible is seventeen inches wide at the bottom, twenty-eight at the top, and reaches five feet eight inches above the base of the furnace. The boshes are nine feet in diameter; the diameter of the top three feet eight inches. The tuyeres are but fifteen inches above the bottom stone. In this furnace, pine charcoal is burnt; the ore used is a yellow hydrate of iron, soft

and friable, somewhat resembling common yellow loam. A very fine foundry iron, remarkable for its liquidity, running into the finest sand moulds, is the product of this furnace. From this metal the greater part of the fine Berlin castings are manufactured. This furnace is remarkable on account of the small amount of coal it uses.

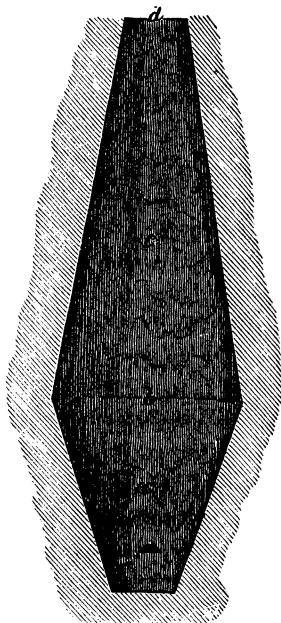
Fig. 55 exhibits a German blast furnace for the smelting of bog ores by charcoal. Though the bog ores of southern Prussia are celebrated for producing very cold-short iron, yet from this furnace a large number of good cannon have been cast for the use of government. The form of the inside of this furnace varies remarkably from that of other furnaces. The height of the furnace

Fig. 55.



Interior of a blast furnace for bog ore.

Fig. 56.



Interior of a blast furnace for spathic ore.

is thirty feet. The crucible *a* is at the bottom seventeen, and at the top eighteen, inches in width; its

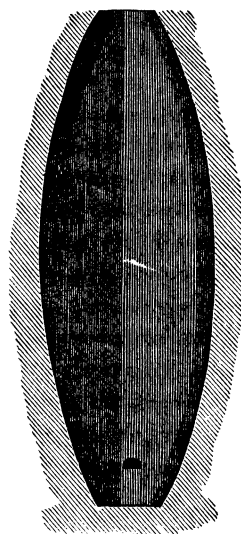
height is five feet six inches. The concave boshes measure, at the widest part, *b*, seven feet. The top, *c*, is three feet four inches in diameter, and forms a cylinder of two feet five inches in length. A very small amount of pine charcoal is sufficient to supply this furnace.

Fig. 56 shows the inside of the furnace at Eisenerz, in Styria, where sparry carbonates are smelted. For want of wood, there were formerly at this spot but thirteen furnaces, mostly of this description. In fact, all the furnaces of the carbonate ore region, that is Styria, Carinthia, and Carniola, are constructed on the same principle. The crucible *a* is generally from ten to thirteen feet high; the boshes *b* eight feet nine inches in diameter; the top *d* from two feet seven to two feet nine inches wide. The height of the furnace is from thirty to thirty-eight feet; so that the upper part of its interior is from twenty to twenty-four feet in height. The blast is produced in square wooden bellows, driven by water-wheels, and conducted to the furnace in two copper tuyeres. The hearth is frequently built of limestone, dry marble, or of Jura limestone. The application of hot blast has never succeeded. So greatly does it injure the quality of the metal, that the forges cannot work it without extreme difficulty. These furnaces seldom have a damstone; the breast is walled up, and a tap-hole for the iron left at the bottom. But in many cases, the cinders flow perpetually from a kind of dam erected on the left side of the breast. The iron is taken out, at short periods, in quantities of 200 or 300 pounds, and commonly run into chill moulds. The pigs are in the form of plates of from five to six feet in length, twelve inches wide, and from two to three inches thick. Such plate iron may be used for making either steel or bar iron; but if designed for bar iron alone, and if the very best bar iron is desired, another mode of casting the metal is practised. The founder digs a circular hole, from twenty-four to thirty inches in diameter, not far from the tapping-hole, into which the iron falls. The surface of the iron is kept very clean, by throwing off the rubbish and cinder. By sprinkling it with a little water from the nose of a

watering-pot, in a very short time the iron on the surface crystallizes, chills, and a plate in the form of a rosette, from one half to three-fourths of an inch thick, is lifted off by means of an iron fork shaped like a hay fork, and laid aside. The freshly opened surface of the liquid iron is treated in the same manner as before; and thus the iron contained in the basin is converted into rosettes, which decrease in diameter as the amount of metal diminishes. These tin plates, of a very rough surface, are excellently adapted for the manufacture of bar iron, as well in the charcoal forge as in the puddling furnace. This plate iron is generally beautifully crystallized, and is of a whitish or mottled color, in which a somewhat reddish tinge is sometimes perceptible. The thicker plates are generally full of little cavities of a round form, occasioned by the disengagement of gases in the liquid iron.

The old furnaces in Sweden generally had the elliptical form of two crucibles—one put upon the other, as shown in the annexed figure. They were often thirty-five feet high, and, in most instances, worked slowly; they consumed but little coal, but yielded only from two to three tons of metal per week. Still, this metal was of good quality, though only from one hundred to one hundred and ten pounds of charcoal were required for one hundred pounds of iron. The modern form of the Swedish blast furnaces closely resembles the form in general use at the present time. They are often from thirty-five to forty feet in height. In Russia, the same principle of construction prevails. The furnaces are generally large, with weak blast, and adapted to economize fuel. The method of constructing these furnaces was bor-

Fig. 57.



Interior of Swedish blast furnace.

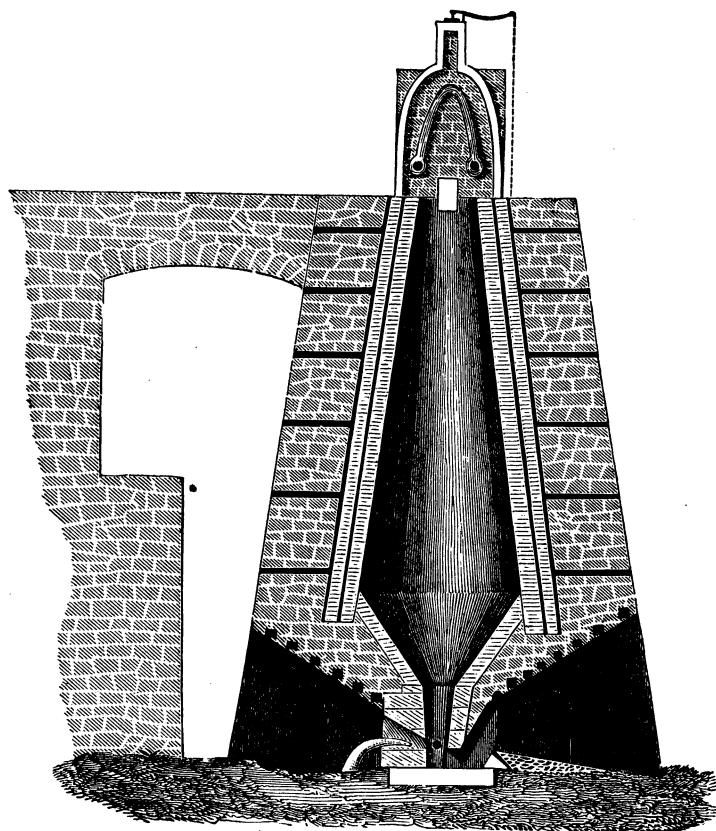
rowed from Germany. In fact the Germans started the iron business in Russia and Sweden, which may account for the great similarity in apparatus.

Before we leave this method, we shall describe a furnace built by the Prussian government on the banks of the Rhine. This furnace is designed for the making of foundry metal from brown iron ore, hydrated oxide of iron. The metal is of good quality, and is used for castings for machinery and cannon; from this metal, also, the finest specimens of ornamental and statuary designs are cast.

Fig. 58 shows a section of the furnace, damstone, and work arch. The height of the furnace is thirty-five feet; nine feet eight inches wide at the boshes; the hearth is five feet high, two feet six inches wide at the top, and two feet at the bottom. The tuyeres are eighteen inches from the base. The top of the furnace is four feet in diameter. The boshes measure, from the upper part of the hearth to its widest part, four feet six inches. The rough masonry of the stack is made of sandstones, strongly secured by iron binders. The hearth was formerly made of sandstone; but at present, I believe it is made of fire brick. Boshes and lining of fire brick. There are two linings, one within the other, between which is a little space, for the purpose of giving room for expansion and contraction; this space is filled with small fragments of furnace cinder. The furnace is built against the hill-side, and the tunnel head bridge sprung upon a wall, raised against the hill. The blast is produced by three iron cylindrical bellows, of double stroke, which so far equalize the blast as to make the application of a regulator superfluous. These bellows are driven by a waterwheel. Two, sometimes three, tuyeres conduct the blast into the furnace, which works with remarkable regularity, and economizes fuel and blast. The hot air apparatus is at the top; and the air is conducted through a system of half circular pipes. The casting-house is built entirely of iron, in a noble Gothic style. It is one hundred feet long, the roof resting upon iron columns of twenty-four inches in diameter. These

columns serve as supports for cranes, by which heavy casting and flasks, the frames holding the sand for cast-

Fig. 58.



German blast furnace.

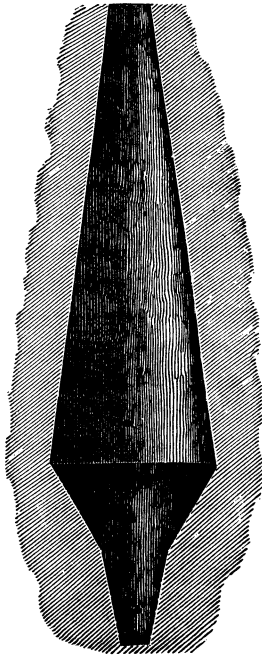
ing, are lifted. In the centre of the building, supported by two rows of columns twenty-four feet in height, runs a strong iron carriage, which serves the purpose of transporting castings from the interior towards the main door, and of lifting them on wagons.

The following are some approved dimensions of American charcoal furnaces in 1850.

The furnace at Cold Spring, New York, was forty feet in height and nine feet in width at the boshes. Its

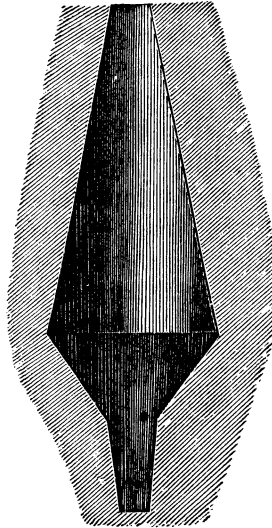
hearth was six feet six inches high; one foot nine inches wide at the bottom, and three feet six inches at the top.

Fig. 59.



Interior of Cold Spring blast furnace.

Fig. 60.



Interior of a Pennsylvania charcoal blast furnace.

In this furnace, magnetic ores from the neighborhood, mixed with a small portion of brown hematite, and a small quantity of bog ore, were those chiefly smelted. The gray pig iron manufactured was of superior quality, very fusible and uniform. Two tons and a third of ore, and 120 bushels of charcoal, were required to make one ton of metal. A very small amount of coal supplied this furnace.

Fig. 60 represents one of the early Pennsylvania furnaces on the Lehigh. The height of this furnace was thirty-two feet; width of boshes nine feet six inches; hearth five feet high, two feet in width at the bottom, and two and a quarter feet at the top. The rich hydrates,

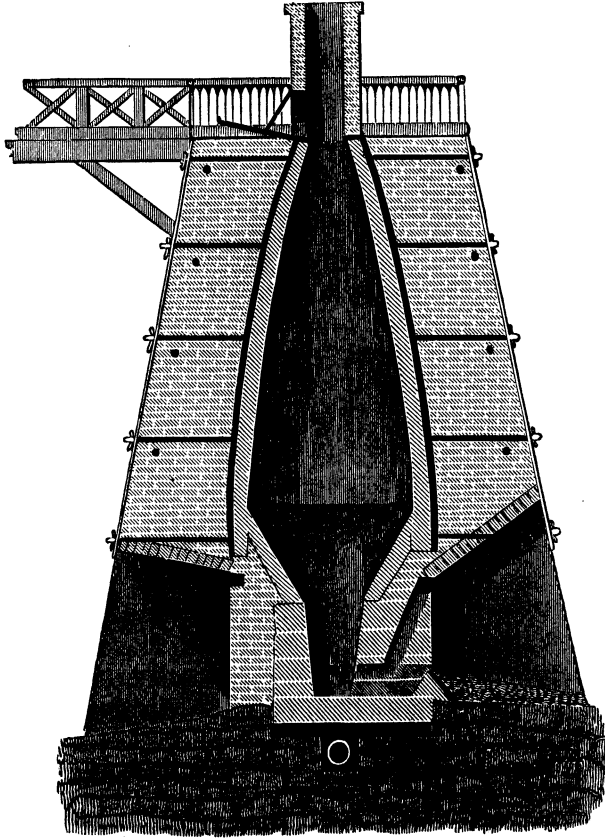
brown hematites, pipe ores, fossil ore, &c., were generally used. Two tons and a half produced, on an average, one ton of metal. For each ton 180 bushels of charcoal were required. At some places, the ore was cheap; while at others, it now costs] five dollars to five $\frac{2.5}{100}$ at the mines for brown hematites (1868) per ton. There were places where formerly (1849) but one dollar per ton was paid for ore, and but four cents per bushel for charcoal. This was the case at Lebanon, and in some adjoining counties. The furnaces in operation at the oldest establishments west of the Alleghany Mountains, such, for instance, as the Dover furnace at the Cumberland River, Tenn., are nearly a copy of those in use in Eastern Pennsylvania. Both require the same amount of fuel, and both yield similar results. But the further we move west, the greater is the amount of coal we find used to produce a given amount of iron. For instance, at the Alleghany and Ohio furnaces, as far down as Hanging Rock and Portsmouth, 170 or 180 bushels of charcoal are considered sufficient to make a ton of iron; while in Kentucky and Tennessee, from 200 to 250 bushels of charcoal are required to produce the same amount. (The above was considered true in 1849.)

The Modern Charcoal Blast Furnace.

At the present time, the blast furnaces are constructed, in a greater or less degree, upon the same principles. While they slightly vary according to ore, fuel, locality, in the main the hearth is narrow and high, the boshes more or less steep, and the tunnel head, or throat, from four to six feet wide. The outward form varies greatly; and every owner or builder follows whatever arrangement is most conformable to his taste. We shall give the result of our own experience, and point out the material points on which the success of smelting mainly depends. Fig. 61 represents a section through work and back arches of a charcoal furnace. This furnace has two tuyeres, and is designed to smelt hydrates of the oxides of iron, such as hematite, brown iron stone,

pipe ore, and bog ores. This form, with more or less alterations, will serve as a general model. The exterior may, in all cases, be the same, and the interior altered according to circumstances. The whole height of the

Fig. 61.

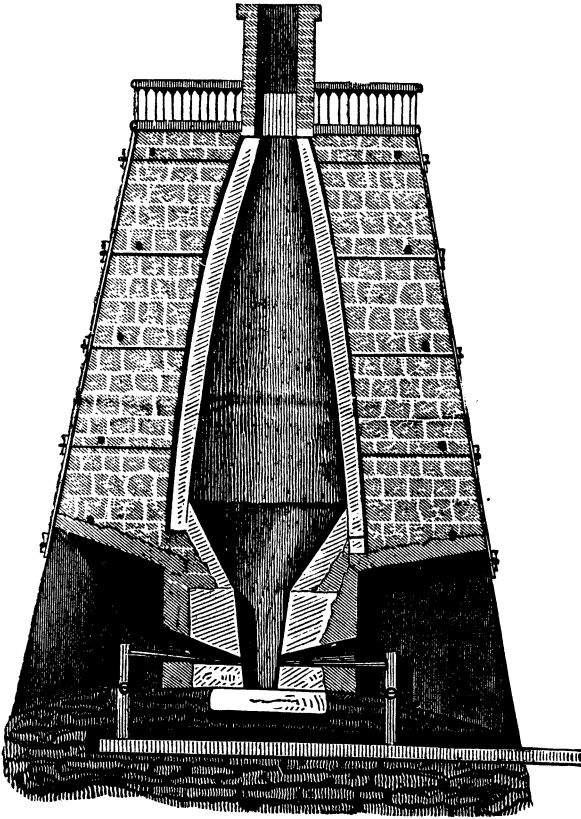


Vertical section of a blast furnace designed for charcoal.

furnace is thirty-five feet. The hearth measures from the base to the boshes five feet six inches; its width at the bottom is twenty-four inches, and at the top thirty-six inches. The tuyeres are twenty inches above the hearth. The boshes are nine feet six inches in diameter and measure from the top of the crucible four feet, thus

giving about 60° slope. The blast is conducted through sheet-iron or cast-iron pipes laid below the bottom stone into the tuyeres. The top is furnished with a chimney, by which the blaze from the tunnel head is drawn off. Around the top is a fence of iron or wood;

Fig. 62.



Section of a charcoal furnace through the tuyere arches.

sometimes of stone. Wood or sheet iron, however, is preferable. Fig. 62 shows the same furnace in a section across the two tuyere arches and the tuyeres.

Coke Furnaces.

The construction of a coke furnace does not materially differ from that of a charcoal furnace, except in its dimensions, and for the heavier pressure of its blast. Its height varies from forty to fifty feet. If the latter height is exceeded, the furnace does not work well.

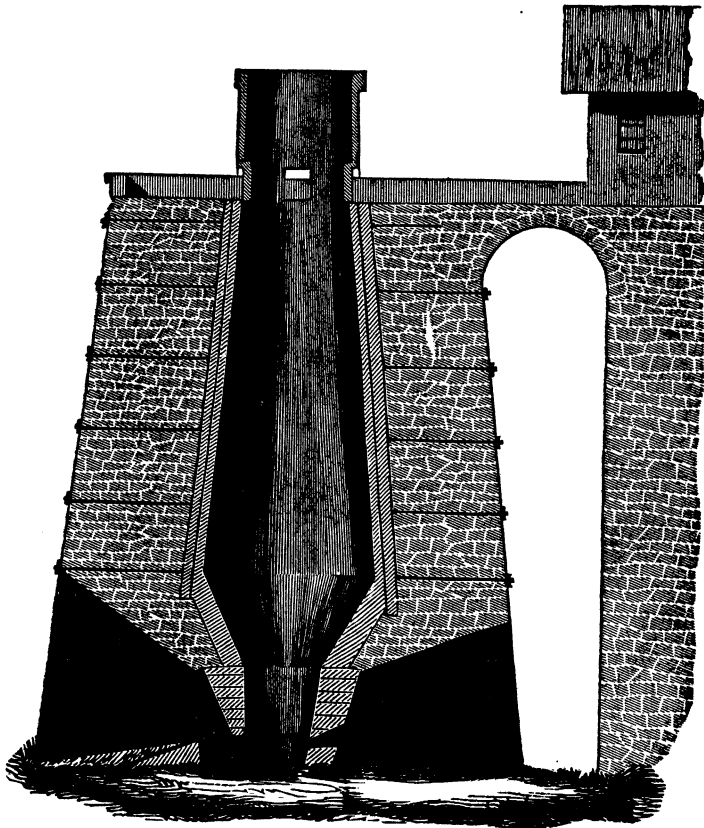
We shall confine ourselves to a description of the coke furnaces of this country, and to a description of a French furnace, which is no less distinguished by its convenient structure than by the excellent work which it produces. Nearly all of the coke furnaces of the United States are of the same form and dimensions; and they were, we believe, copies of the Lonaconing furnace, in Maryland.* This was the first coke furnace erected in this country, whose operation was continuously successful. It is fifty feet high, fifty feet at the base, twenty-five feet at the top, and measures fifteen feet at the boshes. At Mount Savage,† and at the Great Western Iron Works, the only variation from these dimensions is in the size of the throat and the hearth. The Lonaconing furnace has produced good foundry pig metal; this has seldom been the case at Mount Savage, and at the Western Works. The latter, however, succeeded, after many efforts, in making the furnace produce good white metal for the use of their own rolling mill. The Western Works have enjoyed peculiar advantages; but they have also labored under peculiar disadvantages. Their stock, so far as ore, coal, and fluxes are concerned, is cheaper than that of any furnace in the Union; but the coal at their disposal is the outcrop of the two lowest veins in the Pittsburg coal basin. These veins are notoriously very sulphurous. Inasmuch

* Lonaconing, Alleghany Co., Md., situated a quarter of a mile below Lonaconing station, on the Baltimore and Ohio R. R., and bears date 1837, although there was an older charcoal furnace on the site: made, in 1855, 1860 tons of iron from ball and bog ores of the coal measures.

† Nine miles N. W. of Cumberland, in the midst of the Frostburg coal basin, connected with B. and O. R. R. by a branch road eleven miles long. No. 1 was built in 1840.

as the coal of that region is scarce, and of inferior quality, it is a riddle, among iron manufacturers, why these establishments were erected at the precise place where these natural difficulties can never be removed. The works at Mount Savage were erected on an equally inconvenient spot, in the Frostburg coal basin; and they have had to encounter the same difficulties. So far as stonecoal is concerned, Lonaconing appears to be the best

Fig. 63.



Coke furnace, Great Western Iron Work, Pa.

located of the three works. The Western Works enjoy the advantage of a very cheap and good ore, a true argil-

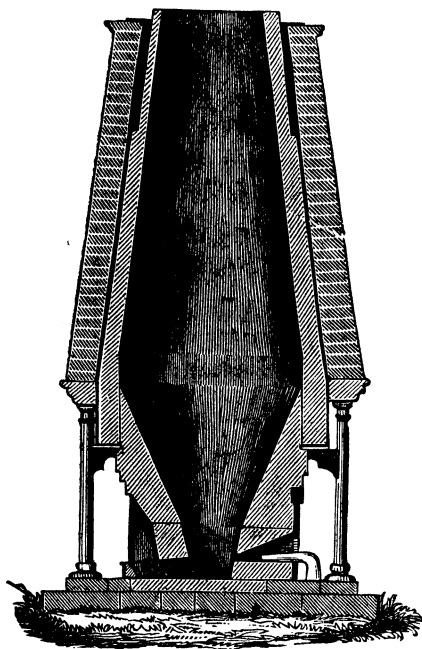
laceous ore, somewhat calcareous, which, in most cases, was formerly laid at the furnace, at from one dollar to one dollar and twenty-five cents per ton. With charcoal, this ore produces an excellent and strong metal, and many expensive experiments were made with it before coke furnaces were brought into a state adapted for regular business. Still, it appears almost impossible to run these furnaces upon gray iron. A whitish, red-short forge pig is the quality constantly manufactured. On what hypothesis this is to be accounted for, we shall hereafter endeavor to explain.

Fig. 63 exhibits a section across the work arch and the back arch, including the bridge-wall of a Great Western furnace. The furnace is provided with six tuyeres, and with hot blast. It produces from seventy to eighty tons of forge iron per week. The lower part of the boshes, which in other furnaces forms the hearth, is about six feet high. This part is made of sandstones from the coal measures; but from this point till it joins the in-wall, it is made of fire-brick. In other respects, this furnace does not materially differ from other furnaces. There is a very low, and considerably tapered upper hearth in one of the furnaces at this place. The boshes reaching down almost to the tuyeres, and that part alone below the tuyere being plumb.

Hyanges Furnace.—At Hyanges, Department Moselle, in France, there are three beautifully constructed blast furnaces for coke, which work admirably. Fig. 64 shows a section across tump and back; and Fig. 65 a front elevation. The stack is forty-six feet in height, and it measures sixteen feet at the boshes; height of hearth six feet, and width of top eight feet. The exterior of the furnace is round; the rough wall rests on cast-iron pillars and cast-iron framework. It is built of hewn sandstone, finely dressed, and bound by wrought-iron hoops. The in-wall is made of fire-brick; the hearth, of a cement composed of roasted and pounded quartz, mixed with fire clay, and pounded in between the cast-iron plates, which form the cloak of the hearth; the boshes are formed of fire-brick, made of the same

material as the hearth, and air dried. The damstone is not in a sloping position, as usual in furnaces; but a vertical dam of fire-brick is erected, in the middle of

Fig 64.

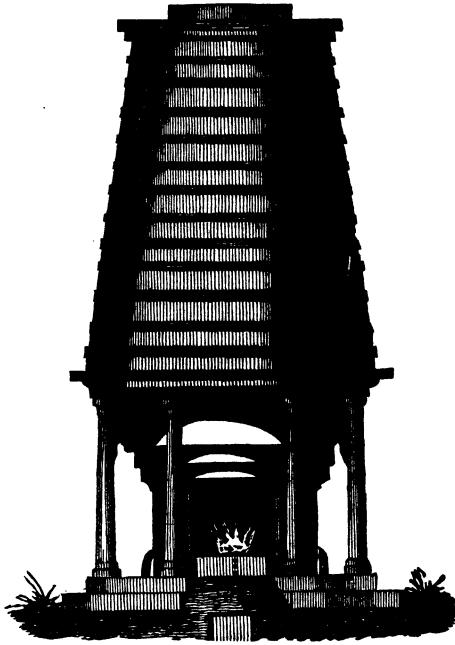


Section of a coke furnace at Hyanges, France.

which holes for tapping the iron are left. The damplate is protected from the overflowing hot cinders by a projecting rib on the top. In these furnaces, brown hydrates, very much resembling the fossiliferous ores of Eastern Pennsylvania, are smelted. The metal produced is very cold-short; but it is wrought into bar iron of the finest forms and shapes. A large amount of it is converted even into sheet iron and tin plates. We shall have occasion to refer to this subject again. In the chapter on puddling, we shall explain the exact process by which this metal is converted into bar iron.

Whatever else is necessary to be said on the subject

Fig. 65.



Front view of a coke furnace—Blast furnace at Hyanges.

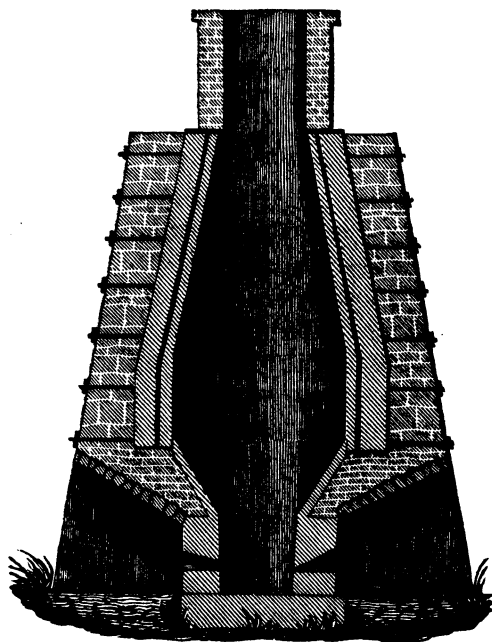
will be found in our general review of furnace manipulations.

Stonecoal Furnaces—Anthracite Furnaces.

Raw coal and anthracite have been employed to a degree which the most sanguine could scarcely have conceived. In Eastern Pennsylvania, a large number of blast furnaces, supplied by anthracite, are, at the present time, in operation. These produce, on an average, from seventy-five or eighty to 200 and some 300 tons of iron per week. In addition to these, many furnaces are now in course of erection. These furnaces are supplied by anthracite coal alone, and the perfection to which they have been brought is a security that nothing can check their prosperity, or prevent their extension in this country.

Anthracite furnaces resemble, to a greater or less degree, coke and charcoal furnaces. They are seldom so high as coke furnaces, and their horizontal dimensions are usually greater than those of charcoal furnaces. To avoid unnecessary repetition, we shall give the dimensions of several of these furnaces recently erected in Eastern Pennsylvania. Fig. 66 represents a cross sec-

Fig. 66.



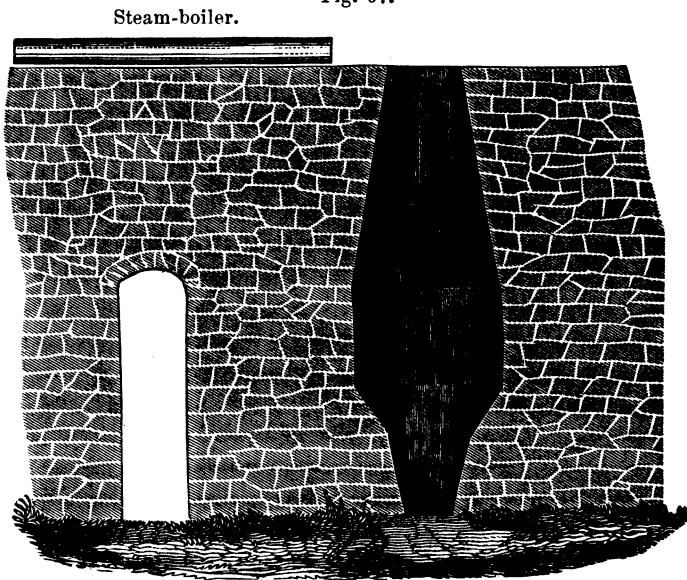
Anthracite furnace at Reading, Pa.

tion of an anthracite furnace at Reading. Its height is thirty-seven and a half feet; the top or throat six feet in diameter; height of hearth five feet; tuyeres twenty-two inches above its bottom; the hearth is five feet square at the base, and six feet at the top. The boshes are inclined sixty-seven and a half degrees, or at the rate of six inches to the foot, and measure fourteen feet at their largest diameter. At the point where the slope of of the boshes joins the lining, a perpendicular, cylin-

drical space, five feet in height, commences; from the latter point the general taper to the throat is continued in a straight line. The hearth, as well as the boshes, is built of coarse sandstone; but the latter are covered with a lining of fire-brick nine inches thick. The in-wall consists of two linings; the interior is the lining which covers the boshes; outside of this is a space four inches wide, filled with coarse sand; and this is protected by a rough lining of slate, two feet thick. The rough walls of the stack are not heavy; but they are well secured by binders.

Two furnaces erected at the Crane Works,* near Allentown, were, in 1850, considered the latest improve-

Fig. 67.



Section of an anthracite furnace at Catasauqua, near Allentown, Pa.

ment. (Fig. 67.) The stack was thirty-five feet high, forty feet square at the base, and at the top thirty-three

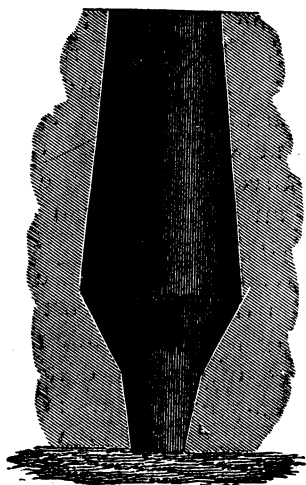
* Four miles above Allentown, at the place now called Catasauqua. There have been four additional stacks built since the above mentioned stacks were finished. No. 6 is the largest and was blown in this spring (1869.)

feet. This furnace was, therefore, but slightly tapered, and required heavy stonework. It generates steam from the tunnel head gas flame. At most anthracite furnaces, this is done by putting the boilers on the top of the furnace. The hearth is five feet high, four feet square at the bottom, and six feet at the top; the inclination of the boshes is 75° , and the cylindrical part of the in-wall above the boshes is eight feet high, and twelve feet in diameter. From the cylindrical part up to the top, which is six feet in width, the in-wall runs in a straight line.

Fig. 68 represents one of Messrs. Reeves and Company's furnaces at Phoenixville, Pa. Its height is thirty-four feet. The hearth is six feet high, four feet three inches square at the bottom, and five feet three inches at the top. The boshes taper 68° , or at the rate of rather less than six inches to the foot. They measure thirteen feet at their widest part. Care should be taken that the lining and the boshes form a gradual curve, that sticking and scaffolding* in the boshes may be obviated. The top of this furnace is eight feet square. There is no doubt that the form and construction of these anthracite furnaces have been carried, within the short space of a few years, to so high a state of perfection as to leave but little room for future improvements.

The practical working of these furnaces will be explained elsewhere. We shall merely remark, in this place, that most of them generate the steam for the mo-

Fig. 68.



Interior of an anthracite furnace at Phoenixville, Pa.

* A term used for the occasional sticking, or hanging of all the charge, or contents of a furnace against its side, and thus preventing its descent.

tive power of the blast, as well as the heat for the hot blast apparatus, at the top of the furnace. In this way, expense is not only saved, but a uniform generation of steam and heating of air are produced. In relation to the building of coke or stonecoal furnaces, it is not necessary to enter into particulars, inasmuch as the principles applicable to these furnaces are applicable to charcoal furnaces. The cost of erecting such a furnace, it is almost impossible to state, for this will depend upon locality, material, wages, and individual tastes. But it may be laid down, as a general rule, that a stonecoal furnace costs less than a coke furnace; and that, in most cases, a good charcoal stack can be altered so as to serve for stonecoal.]

Mr. Overman considered the following true in 1850: In the Western States, many charcoal furnaces are in operation, and there is no limit to their extension, so far as raw material, wood, and ore are concerned. One circumstance, however, will necessitate the introduction of mineral coal furnaces in the West; that is, the price of charcoal iron. Some localities can successfully compete against mineral coal iron; but those which, besides enjoying that advantage, are situated near navigable streams or canals, are very few in number. We believe that the average cost of producing charcoal pig at Pittsburg is twenty dollars; some furnaces produce it at a cost of fifteen dollars. In as many cases, however, twenty-five dollars is paid for iron. The market price at Pittsburg has varied, for the last two years, from twenty-five to thirty dollars, according to quality. At this price, but little profit is left to the owners of the furnaces. How far the stonecoal furnaces are in advance of this, will be shown by the following statement of the average result of three years' smelting. This statement has been furnished by Mr. Reeves, of Philadelphia:—

Amount of material consumed to produce one ton of Iron at anthracite furnace No. 1, at Phoenixville.

Iron ore	2.59 tons.
Anthracite coal	1.83 ton.
Lime	1.14 "

Amount consumed at furnace No. 2, at the same place.

Iron ore	2.65 tons.
Anthracite coal	1.89 ton.
Lime	1.15 "

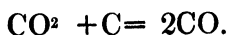
Which form is the best for a Blast Furnace?

We shall preface our remarks, by introducing the results of some examinations by a former pupil and assistant, Mr. Charles McIntyre, Jr., who has paid particular attention to this subject.

The best form of a blast furnace is, undoubtedly, that form which, with the least expenditure of blast and fuel, will produce the most and best iron, all other things being equal. Or, in other words, the ore flux and quality of iron being constant, the best form is that which produces the most iron with the least blast and coal, and with the greatest regularity. We have here three variables, fuel, blast, and quantity of iron; the consideration of which we will take up in succession, and see to what results we shall arrive, then by harmonizing these results, we may arrive, clearly and fairly, to a just conclusion.

It is necessary, however, at the beginning, to inquire what are the operations, which occur in a blast furnace, when it is in good working order? All workable ores of iron are oxides of the metal in combination with impurities of various kinds; to eliminate these impurities we use fluxes. To rid ourselves of the oxygen, we must employ an agent which has greater affinity for oxygen than iron; this is carbon. In order to supply carbon to the oxide of iron, we must make it carbonic oxide, (CO), hence the blast. The oxygen of the atmosphere

passing in upon the ignited fuel, becomes carbonic acid, (CO^2), while the greater part of the nitrogen escapes out of the tunnel head unchanged; the formation of carbonic acid (CO^2) is attended with great combustion and heat, but as the carbonic acid (CO^2) passes upward, it meets with an excess of carbon, loses an atom of oxygen, and becomes carbonic oxide (CO),



this is attended with an absorption of heat, and accounts for the reduction of temperature above the crucible; thus, for every volume of carbonic acid (CO^2) we have two of carbonic oxide (CO), this unites with any carburized hydrogen of the fuel, and passes up as a combustible gas. The descending ores being made porous in the upper part of the furnace, are permeable to the ascending gases, and the iron begins to be reduced in the upper part of the boshes; as it descends to the hotter part of the furnace, the flux and impurities melt and form slag, while the iron in minute particles unites with the carbon of the fuel, and forms that carburized iron, called cast iron, which melts, falls through the slag, and is drawn off from the bottom of the crucible.

Hence we see that in different parts of the same furnace different operations are going on: these parts have been classified into four different zones of specific heat, by metallurgists, who have founded the classification upon actual experiments. These zones are, beginning at the top: I. The zone of preparation; II. The zone of deoxidation or reduction; III. The zone of carburization; IV. The zone of fusion. These zones are all laid down, as to their exact locality, by some writers; while others show conclusively that they are rather relative distances, than absolutely so many feet and inches distant from any point.

Having set before us the work performed by a furnace, we are prepared to take into consideration, what shape will best perform this work? In our discussion we assume the furnaces to be using the same kind of fuel, ore, and flux, prepared in the same manner, and the

blast of a uniform temperature ; for only by considering the condition as equal, can we arrive at a fair conclusion. Having these things constant, our object is to shape a furnace which will use a minimum amount of coal and blast, and produce a maximum amount of iron. We shall treat of the amount of coal and blast together, as they are closely connected ; for if a less amount of heat can be efficiently used, less coal and blast is required ; or if less gas is needed, we can work with a smaller pressure and less fuel. The shape of the furnace must be such as to allow the heat to expend as much force as possible, with satisfactory results.

Were mere uniformity of distribution of heat the only consideration, we could make the furnace cylindrical, and the section would be represented as in Fig. 69 ; for, in such a shape, the heat would be applied to the greatest amount of material from tuyere up to tunnel-head. In this form, however, the pressure from material above would make the molten mass below so dense as to hinder

Fig. 69.

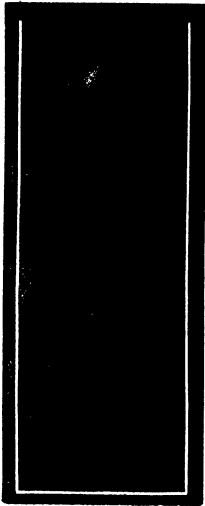
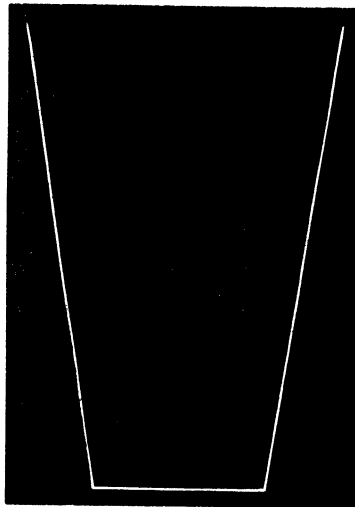


Fig. 70.



the passage of the blast, consequently hindering the operations of the furnace. We must therefore arrange

the shape to support some of the superincumbent pressure. We can do this by battering the walls, as in Fig. 70. But in this shape two difficulties present themselves: 1st. Where the furnace is largest the heat is most expended, and cannot have full influence in preparing the charge. 2d. The tendency of heat is to expand the mass, and before fusion, this expansion, however small it may be, increases the space between the individual pieces of the charge, and more room is required for the same amount of material; and by contracting the form under these circumstances, there is danger of scaffold-

Fig. 71.

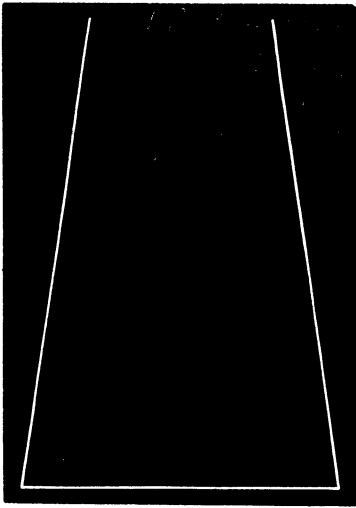
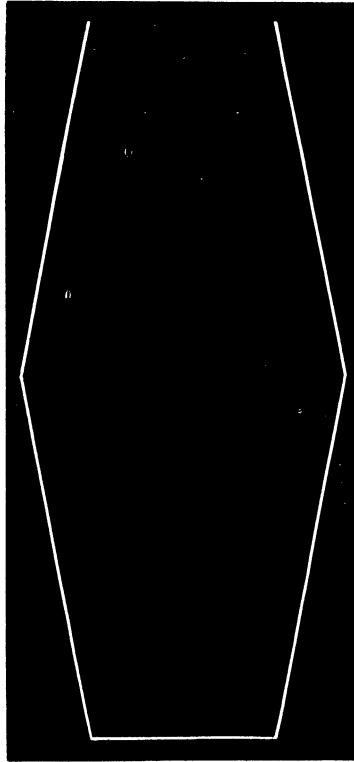


Fig. 72.



ing. For these reasons a furnace, whose shape is the reverse, would answer, as in Fig. 71. But this would

be condemned for the same reason that the cylindrical form was condemned.

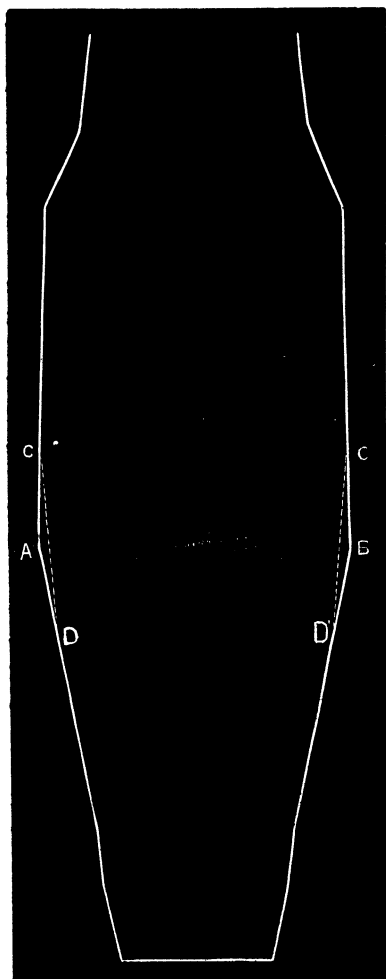
We want, therefore, the superincumbent material supported, and the furnace to enlarge from the tunnel head downwards, in order to allow for the expansion of the ore. By uniting the last two forms, and forming a furnace shaped as in Fig. 72, we fulfil these conditions. In this form our objections, thus far raised, are removed, the unfused mass is supported, and descent is allowed to the ores; when fused, being able to flow, they will fill up the interstices, and thus the diameter of the furnace can be decreased without hurt; the heat is likewise better applied beyond the intense heat in the crucible, and after the reduction of CO^2 into carbonic oxide, it passes through the deoxidizing zone, fully prepared to do further duty, and, as it cools, the drawing in of the walls concentrates its efficiency. This, then, is the fundamental form; how shall it be modified so as to make the best form?

We have not as yet spoken of the inclination the two frustra should bear to each other, and this is a very important consideration, when we ask the question, How shall the deoxidizing material be applied to the ore? If the stack be narrow at the boshes, and the angle at the boshes large, the charge will be crowded together so that a comparatively small quantity will be brought in contact with the gases, at the point where they can be efficient, and there will be an excess and waste of deoxidizing material; but if the angle be too small, there will be more ore exposed than can properly be reduced, and a greater amount of coal would be needed. Even if we take great pains, and make the angle of a medium size, so that we will escape both difficulties, there would still be a space where the ore would not be fully spread, and hence not fully exposed to the ascending current.

By altering the shape somewhat, and making it of a shape as represented by Fig. 73, we will, observing the former precautions and making it of the right width, be able to expose the roasted charge for a longer period to the deoxidizing gases. This then is an improvement

on the previous form. But in this figure, we have angles at A and B (Fig. 73), of a greater or less size; these

Fig. 73.



Blast furnace No. 2, Scranton, Pa., April, 1868. Scale 10 feet to one inch.

may catch some of the most refractory substances, be in some degree shielded from proper influences, and cause scaffolding; the friction is also increased by these angles, and the flow of materials is neither easy nor

uniform. How shall we remedy this defect? Suppose we had a furnace of this kind scaffold at A B, how should we change the internal shape to prevent a repetition of this? One way would be to ease off by changing the shape of the lining, bringing it out to C D; but here we have two angles instead of one, or, rather, have two bases of resistance, which would be abrupt rather than gradual; this would increase the friction, rather than simply sustain the load, and the tendency would be to scaffold in other places; again, we may destroy the angles by straight lines, and by continuing this process we have a curve. This curved form of lining fulfils all conditions we have advanced; it is essentially the form of two frustra of cones, placed base to base, which we have concluded to be the fundamental form; the curve nearest the widest part is very gradual, so that it has an equal advantage with those whose middle part is cylindrical; having no sharp angles, the liability of scaffolding is decreased, and there is the least possible friction in descending with the greatest proper sustenance of the charges.

But our problem is not yet fully solved; let us review briefly, in order to progress clearly; we first found that a furnace whose lining could be represented by a cylinder, capped on each end by a frustrum of a cone, would economize heat, and apply the deoxidizing agent in the most effectual manner; our next step was to show, that by softening the angles into one general curve, would not alter the effect of the previous form, and in addition would aid the descent of the materials, and lessen the liability of scaffolding; these things we showed particularly in reference to the amount of coal and blast.

We shall next endeavor to show the best form for the quantity of iron. If the furnace was of the form as shown in Fig. 69, the superincumbent pressure would increase the density of the fused and pasty material, and retard the blast; hence the ore would not be prepared and deoxidized as fast as it could be fused; this would eventually cause too much unprepared matter, and could

not, therefore, produce the largest amount of acceptable iron.

In the next shape (Fig. 70), while the pressure is taken off the fused mass, the heat is most expended where a part is useless, being sent up through the middle of the mass, or else being spread over a large surface, it will not sufficiently prepare the ore, which will take a longer time to be reduced when it sinks in the furnace, and hence a longer time to make the metal.

If we make use of the form in Fig. 71, while the blast is properly contracted for the preparation of the ore, the fused material is spread over so broad a space, as to cause fresh material to sink more rapidly than it can be properly prepared, bringing down with it substances which should have been volatilized, and at the same time it has all the disadvantages of Fig. 69.

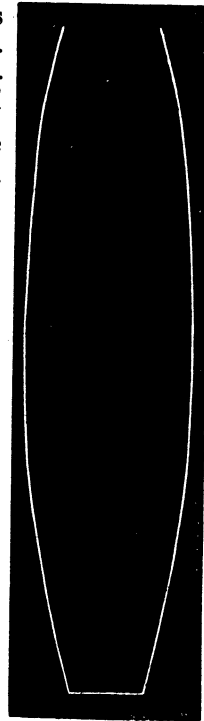
If we make use of the fundamental form (Fig. 72), the heat will, in the general, be properly directed, expanded at the right place, and contracted correctly; but in the way it is applied for a small distance at the widest part, it can only act efficiently upon the central body and the mass in the circular angle must be more or less unaffected; and the ore, in some places, would be prepared faster than it was in others, which would retard the process.

If we try the shape in Fig. 73, the blast is properly directed, as in the former case, and also a greater amount can be deoxidized at the same time, and we can reduce much more rapidly. This will fulfil all our conditions, if we are able to place the angles in the proper position, for, in making furnaces of this shape, it seems as if we mark the place for such an operation to be performed. But can we so make a furnace? Can we, in the first place, build a furnace as to have the zones in the place assigned? And, secondly, do the zones continually remain in the same place? We answer to both questions, no! There may be, at any time, some little change in the ore or fuel, which would of itself alter their position considerably; and this would change the zones, making them to vary at different times. Percy, in speaking on this subject, says: "Even in the same

furnace, with the same charges of ore, fuel and flux, these zones of specific heat may not have precisely the same position at different times, as it has been hitherto found impossible to insure uniform results from any furnace, though working under apparently identical conditions." The results above mentioned have reference to experiments tried in order to ascertain the temperature. This being the case, we are liable to lose in adopting the shape under consideration. How shall we remedy it? If we can so construct a furnace, that a few feet will not materially alter the functions, we have succeeded. Let us apply the test to the curved form, as follows, Fig. 74, it will answer in every respect as well as the last shape, and being curved from crucible to tunnel head, the operations may occur at different places, at different times, without materially altering the working of the furnace; and by assigning no particular position for the zones we allow them to vary without damage; hence we conclude, that the curved form produces the maximum amount of iron, with the minimum amount of fuel and blast, and, with the most constant results.

Another important consideration is economy. It has been observed, that the lining of furnaces which have been running for several years, and then blown out, have assumed the form of a curve approximating the arc of a circle. Now if we build furnaces in the form cut out by the fire, we have the shape it naturally assumes, without falling back upon the fire to do an unnecessary work for us. So that we may assume the furnace will last longer; facts might be mentioned which corroborate this assertion. A furnace of the form given in the last figure, has now been in blast for some

Fig. 74.



No. 5 furnace, Glendon, 1 mile above Easton, Pa., 1868. Scale 20 ft. to 1 in.

months, with great success, as to regularity of working, and excellence in yield, although blown in a little too rapidly in the winter season, causing some cracks in the outer wall. As to the actual middle and height of a furnace, and as to the proportion between the height and middle, these vary, and are governed by the kind of ore, flux, and fuel.

But the conclusion is, that the curved form is the best form of a blast furnace, and will, we believe, stand the test.

The general impression among practical and experienced iron masters is, that the "egg shell" form of the furnace is, after all, the best form for both coke and anthracite. As one of the most experienced iron masters, formerly of Wales, but now in this country, Mr. David Thomas, of Catasauqua, expressed it to us: There is a principle which we must adopt, namely, that the contents of a furnace must be smoothly and constantly on the move, and that form which is most conducive to this regularly constant move, is the form most favorable.

In the coke furnace, however, we have that fuel which, being more friable, of rougher surface, and more easily heated, is more likely to be grasped by the surrounding charge, or elements of the charge. It is less likely to move—it is more likely therefore to stick, and, consequently, the sides of a coke furnace should be accommodated to this fact, that coke will not move, or roll about as easily as anthracite. The sides should therefore be steeper, the stack more slender. Otherwise the form is the same as in anthracite, namely, that of elongated arcs, reaching to the hearth, as in the Glendon furnace form, or to the top of the crucible, as in the Corngreaves pattern, Staffordshire, England, a working plan of which we have given in full in the plates at the close of this volume. We think all the necessities of the furnace are more fully met in this latter form than in any other of the countless variations given and executed. Eventually, this will be the general form adopted, because of its simplicity of construction, and the uniform support and descent which it offers to the charges

of the furnace, and because of the uniform ascent to the heat and the gases engendered.

There must needs be judgment exercised in the formation of that cone, that it be conformable to the fundamental conditions specified in the above pages. As the coke form of the Staffordshire type seems to be perfectly satisfactory, we have, after much inquiry and consultation, come to the conclusion, that this curve, the elements of the ordinates and full measures being given

Fig. 75.

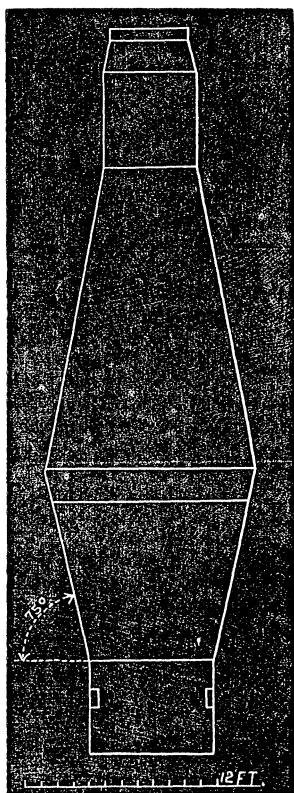
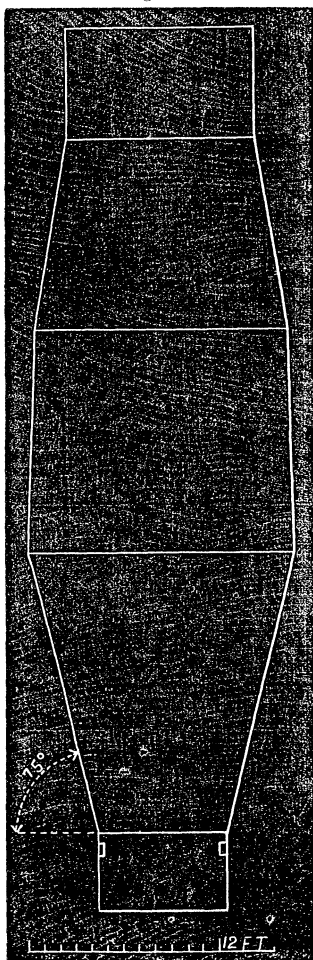


Fig. 76.



in plate I at the end of this work, should be, for the anthracite furnaces (east of the Alleghany Mountains) about 50 feet radius at the bosh, or at the greatest diameter, giving it about 75° slope for the boshes; but, for the cokes, west of the Alleghany, we should adopt the diameter intended to be represented in the drawing, namely, that of 60 feet radius at the same place, or 80° slope. A variation of two, or even three feet, in the radius may not be injurious, because of the smallness of the corresponding variation of slope; nevertheless, the character of the anthracite intended to be used must be made an element in the calculation which varies from the above type. The harder and the smoother the coal the greater may be the variation, within the above limits.

It is not necessary to exhibit all the types of internal form adopted in Europe, or even in this country, although it might add somewhat to our information, but of those furnaces, the forms of which we have given below, it can be said, in all cases, that they have been considered successful, so far as results are concerned.

Fig. 75 is the present form (1869) of the stack No. 2 at Lehigh Crane Iron Works, Catasauqua, on the Lehigh, Pennsylvania. This stack was erected next after the first successful anthracite furnace upon the Lehigh, No. 1 stack being the oldest.

Fig. 76 is stack No. 4, at the same works, erected afterward, and upon a plan supposed to be an improvement. Both of these forms make excellent No. 1 anthracite iron.

Fig. 77 represents a vertical section of stack No. 1, at Carbon Iron Company, Parryville, on the Lehigh, Pennsylvania, which works very well.

Fig. 78 represents a similar section of a stack which is supposed to possess special advantages, and which was completed and blown in last year (1868) at Lock Ridge Iron Company, near Alburty Station, a few miles from Allentown, Pa., on the East Pennsylvania Railroad.

Fig. 79 represents the "Ringwall" or inner section, as

Fig. 77.

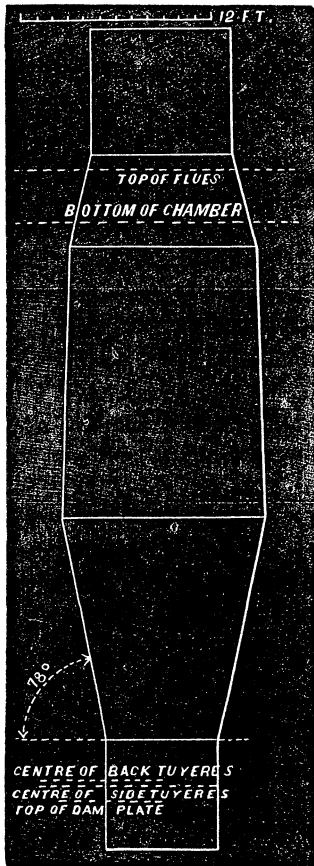
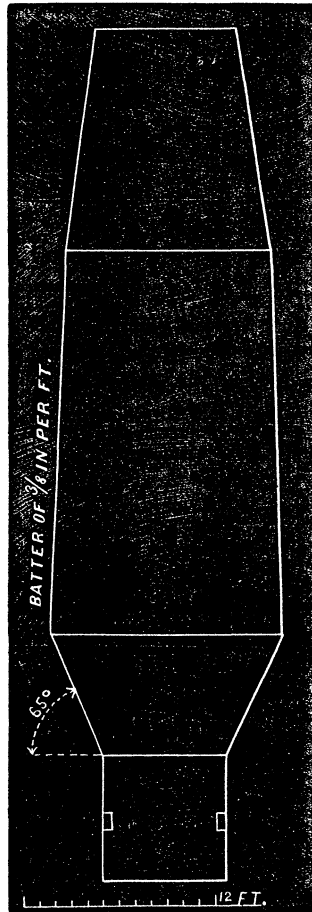


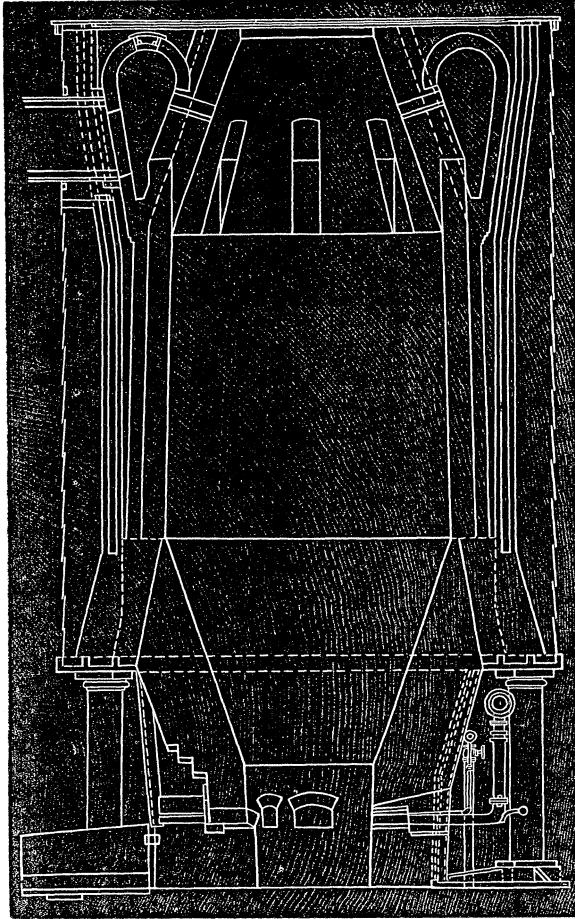
Fig. 78.



well as various other sections, of a boiler iron and iron column furnace at Saucon Iron Works, Hellertown, 3 miles south of Bethlehem, Pennsylvania, on the North Pennsylvania Railroad.

All these furnaces are making more or less gray iron of finest quality, otherwise called No. 1 foundry iron, the kind prepared for foundry castings. (For further distinctions see Effects of Carbon upon Iron.)

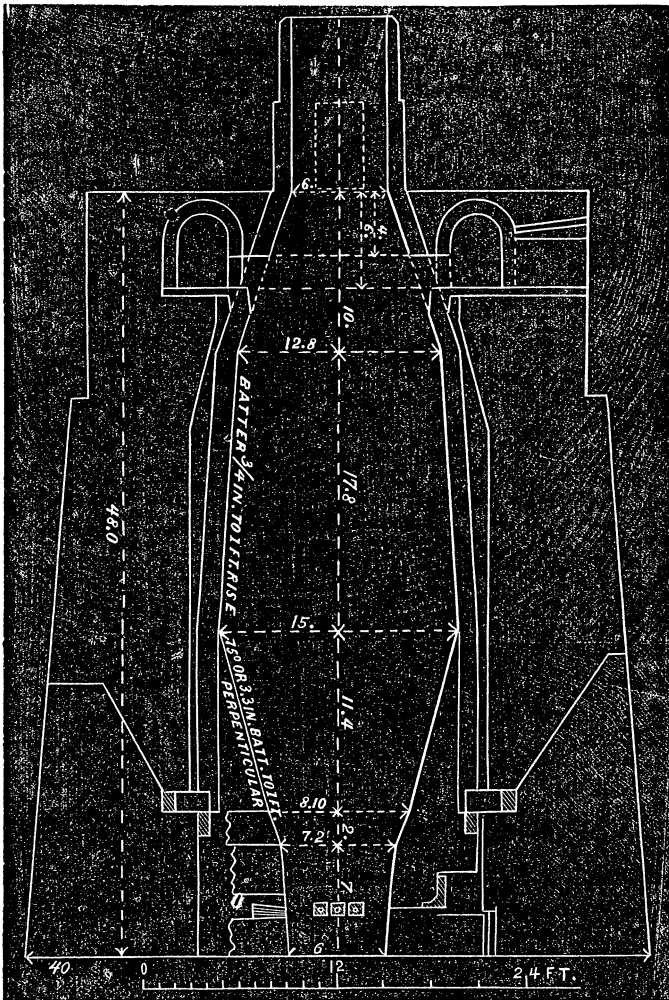
Fig. 79.



There is no radical distinction to be made between the internal form of furnaces making foundry and those making forge iron. But the following forms are forms of furnaces making successfully a high order of forge iron, intended for the large rolling mills and puddling furnaces at Scranton, Pa., on the Delaware, Lackawanna and Western R. R. These furnaces have been under the direction and alteration of C. F. Mattes, a gentleman of thoroughly practical and liberal views and of large

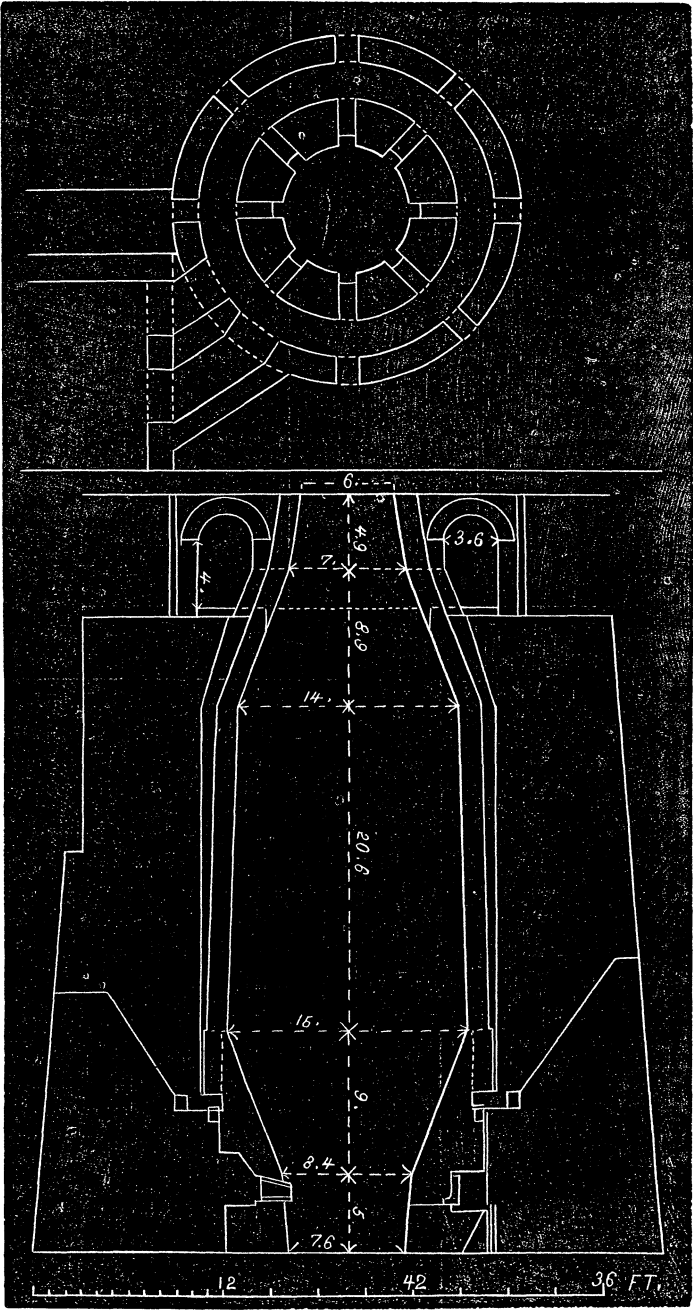
experience. The furnaces of later date are, we believe, upon his own suggestions. The following is one of 1856, furnace No. 3, having a rather peculiar slope just

Fig. 80.



over the crucible. This was afterwards altered as these angles, offering always a more prominent surface to the action of the fire, disappeared, and, therefore, whatever

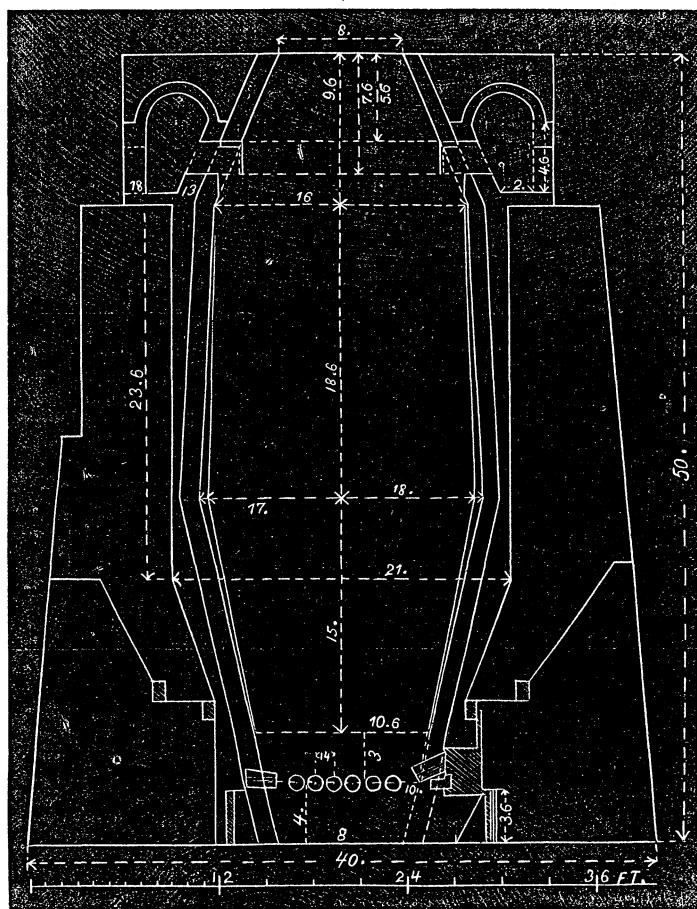
Fig. 81.



benefit they might have presented at first, soon ceased to be available. In January, 1858, we have, therefore, the form of Fig. 81, wherein the angle just spoken of is eliminated and the furnace widened. We have added the arrangement of the arches and circular flue at tunnel head.

In 1862 it was thought advisable to add to the num-

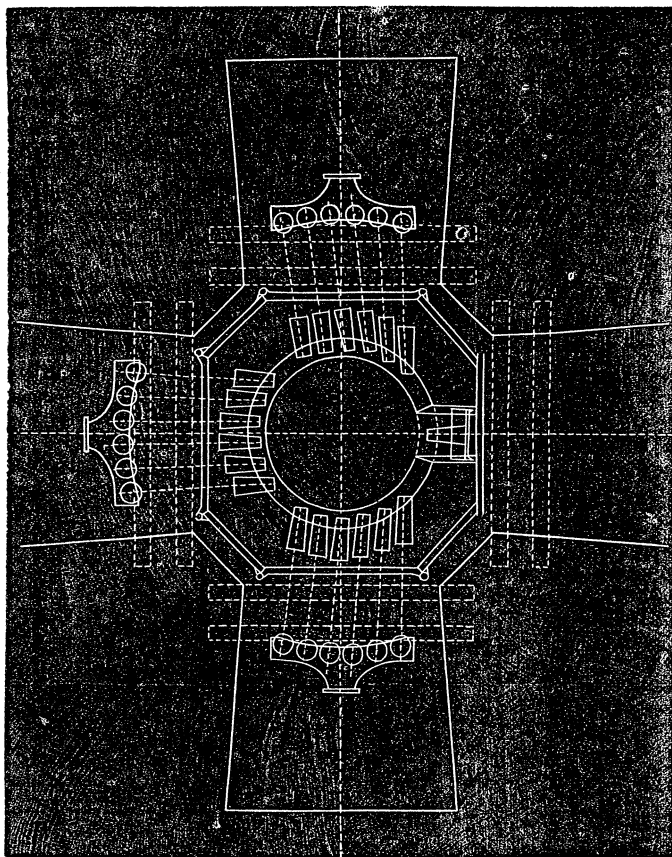
Fig. 82.



ber of tuyeres, and a form was adopted as in Fig. 82, (vertical section), the arrangement of the tuyeres being

as in Fig. 83 (plan), in which 19 tuyeres were introduced, and the furnace widened in the boshes. But

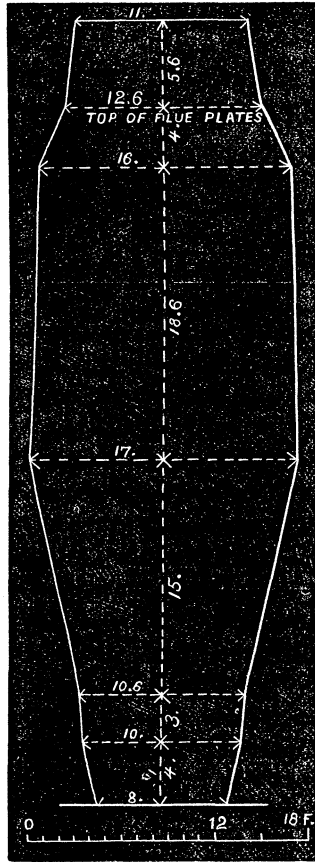
Fig. 83.



this number was reduced, and alternate tuyeres removed with better results. In April, 1868, supposed improvements were suggested, and the form indicated in Fig. 84 was settled upon, as superior to all hitherto adopted. This furnace, at the works, is called No. 2. It will be noticed that if the angles be modified into the most readily made curve, that curve will be nearly that of the form of Glendon furnace spoken of in a former part of these remarks, with this exception, that, where the gas is car-

ried off for the blast oven and the boilers, it is suddenly drawn in to effect a more ready delivery of the gas upon

Fig. 84.



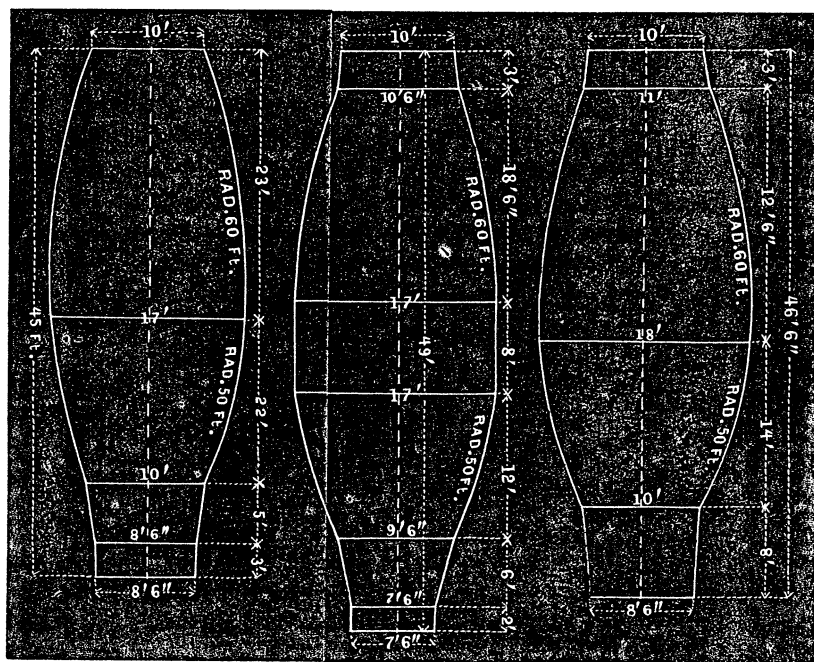
its destined course. All these furnaces make forge iron.

Furnaces of boiler-iron and cast-iron columns are now beginning more generally to be adopted. The finest models of this class of furnaces in this country, are perhaps to be found in Pennsylvania, although some good forms are found in New York, and up the Hudson and on Lake Champlain. The one we would direct attention to, as a good model, the plan of which is adopted in

Pottstown, Lime Ridge and elsewhere in Pennsylvania, is found at Saucon Works, as before referred to. Its form we have already given p. 328. The satisfactory results and the regularity of the furnace operations, seem to suggest, among other elements, the general form of internal structure to which we have alluded. A very complete example of this kind of furnace has lately been put into blast under the plan and management of Mr. John Horton, a few miles from Rochester, N. Y. The height is 50 feet, bosh 14, with a difference from the last in that the ring wall of the stack is surrounded by an air-chamber.

That the uniform curve is beginning to be adopted in England, as the best form, seems apparent, from the out-

Fig. 85.



lines (Fig. 85), which are those of the Dowlais furnaces, considered at that place as the latest and most approved coke furnaces, and, when the outlines were sent us this year, 1869, these furnaces were working quite satisfactorily.

Remarks upon the Construction of Furnaces in general.

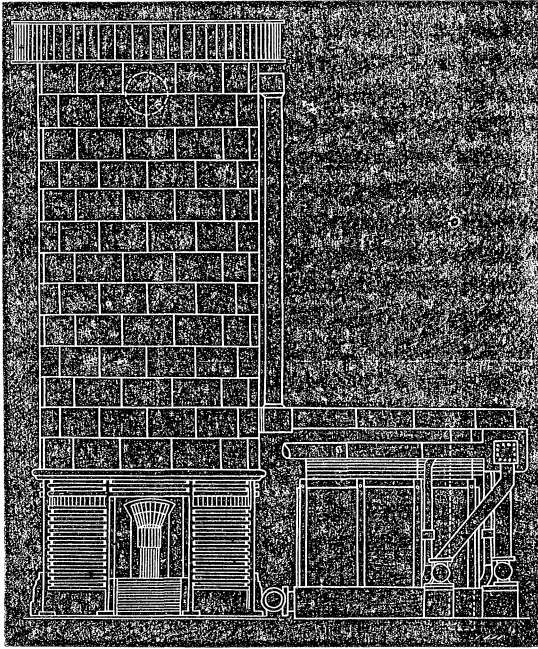
Of all the furnaces in our country, the most imposing in appearance, are those upon the Lehigh. And perhaps the largest and most complete in all their appointments are those at Hokendauqua, near Allentown, Pa., and at Catasauqua, a mile below (for size of engines. &c., see p. 200). After these the next in size, having reference to engines and all other appliances, are to be found at Scranton, Penna., exactly 100 miles N. W. from New York city; the former places are exactly 50 miles N. by 10° W. of Philadelphia. There are others almost equally massive, at Phillipsburg, N. J.; at Allentown, Penn., and elsewhere, but in perfection of parts and largeness of machinery and furnaces, together with novelty of plan, none are superior to those first mentioned. The furnaces at Hokendauqua, as well as those at Catasauqua, are under the direction of gentlemen who, so far as anthracite furnaces are concerned, have as large, as varied, and as practical experience as any in the United States, and they have education and sound practical science to guide them. Mr. David Thomas, of the Crane Works, as we have said, was the first to introduce successfully, at Ynniscedwin, anthracite coal into the iron furnace. Messrs. John and Samuel Thomas have grafted science and large mechanical genius upon the experience and practice of Mr. David Thomas, the honored father of the "anthracite practice," if we may be permitted to call it such. Mr. Joshua Hunt, superintendent of the Crane furnace, is a man of eminent skill, careful observation, and of experience. When, therefore, the minutiae of construction is demanded, beyond that which we are enabled to present in a work so limited as this, perhaps our best plan would be to recommend a visit to these, the largest works in the country for anthracite foundry iron. The same recommendation might well be made, as respects forge iron and rolling-mill iron, in connection with the works at Scranton, under the guidance and management of Mr. C. F. Mattes, whose success is due to long expe-

rience, skill, and judgment, with careful examination of furnaces in this country, and lately in Great Britain and the Continent.

All these furnaces, however, are of stone construction, the latest of which, and the largest, is No. 6, at Crane Works, Catsauqua. The one at Lock Ridge is not so large, but has all the latest appliances of a new furnace, together with the new Lurmann's improved front cinder-block (as in No 6, above-mentioned), of which we shall speak. Of the boiler iron (cupola) furnaces, several have lately been finished at various places in New York and Pennsylvania, and several are now in process of erection, which are excellent types. In the Saucon iron works the stack is lined, first with two courses of fire-brick 16 inches thick for the two courses, then a space filled with loam, then brick, then ashes, brick, loose sandstone, and finally the iron casing, as we have represented in Fig. 79. Some have used a lining of broken cinders, and others again a lining, in place of cinders, of broken sandstone, and then the boiler iron in the usual plates. The air-chamber, referred to in our notice of the Rochester furnace, works well. Mr. Horton informs us that during March, 1869, he made 900 tons foundry iron with about one ton and a half Luzerne Co. anthracite to the ton of pig. In Fig. 86 there is a representation of a blast furnace at Ebbw Vale [Eb'-bu Vale], Monmouthshire—front elevation, with hot-blast stoves on the ground-level. It will be noticed, by the bases, that the columns are not so large as in the American type, which may be considered "massive." In other respects, omitting some details, the general form and the outline of interior make it resemble the Saucon furnace. The internal arrangement of various materials for filling, we think of greater importance than the air-chamber, since it more fully forestalls loss of heat from minute fissures, therefore is more economical, and because conducive to a proper elasticity of the walls while, at the same time, there is greater solidity and distributed support. As we shall see under "Charges," large yield of iron is not in *every case* decisive as to impermeability of the walls of a furnace. The

more thoroughly a wall is made non-conducting, the surer are all contingent effects to be favorable, and the more frequently a wall of a furnace is divided, consistently with strength and infusibility, the more is heat

Fig. 86.



retained. How far this division may proceed, must depend upon the judgment of the builder; but few only appreciate the fact, that much success depends upon apparently so small a cause as retention and management of the heat expended within, and sometimes through, the walls of a blast furnace.

High Furnaces.

Of late years considerable attention has been directed to the increased height of furnaces. The advantages claimed are, 1st. Economy in fuel; 2d. Larger yield in iron. So far as the theory is concerned we believe that

the claims are well founded, and eventually the advantages claimed will be generally realized. But in some cases these advantages do not seem to appear to so great an extent and in so decided a manner as was at first expected. 1. The heat hitherto expended at the top of the furnace and which could not be otherwise utilized, it was supposed might be made to pass through the ore and other parts of the charge, and thus be expended to some purpose of economy. This was a just hope upon good grounds, and it has been fulfilled. The 2d advantage would naturally follow, for if the ore was in a more advanced state of preparation before it arrived at that point of the furnace at which, in the lower stacks, it had not been prepared, it is plain that it would be nearer reduction and consequently would fuse more rapidly, and more iron would be the result. But in practice it has been found that, generally, the higher the stack the more resistance was offered to the blast. This demanded more pressure, more steam, and more wear and tear, if not more fuel. Moreover, the higher the stack the greater the pressure upon the lower zone of coal in the furnace, and the more likelihood of crushing the coal and causing greater obstruction to the blast and to regular working. Now these difficulties have brought it to pass that while in some furnaces, erected upon this high plan, there has been great success, in others the success has been doubtful when compared with the exceeding amount of outlay. Supposing that the coke, or fuel, is sufficiently hard to bear the resistance of pressure and thus leave the furnace charges open, not causing much difference in the resistance to the blast, and supposing that the ore is not so soft, or small and friable as to run through the interstices, and act in the manner intimated in the case of soft coke or coal; these facts would seem to insure success when all other elements in the furnace treatment are modified accordingly. We have evidences of the economical value of such enlargement, for height in this case is followed by the enlargement of the bosh, and the results, practically, are more metal made by the same number of hands, the same expenditure of fuel, and the

pro rata being taken, the same capital invested. As for improved quality of metal, the benefit resulting from prolonged roasting is not great, as in several instances the entire closing of the furnace throat, forcing the air through the passages of the flues, serves in some degree to condense or throw back the volatile elements upon the charges, and the additional height, while, theoretically, it gives much more time for heating, with such tenacious elements as sulphur, phosphorus, and zinc or arsenic, will give but little essential benefit, so that we may not add great improvement of the metal to the other advantages. We shall present some instances of this increased height and the associated advantages and disadvantages claimed and objected, and, after the above remarks we shall be able to examine into the comparative merits.

John Player's "Monster Blast Furnace" at Norton, near Stockton-on-Tees, England, is 85 feet high and 25 feet across the boshes; cubic contents 26,000 feet with closed top, and the bell and hopper arrangement for charging; has one horizontal blast engine; blowing cylinder 7 feet in diameter by 7 feet stroke, working 22 revolutions per minute. Has 4 of Player's Patent Double Hot Blast Stoves, of 30 pipes each, heating the blast 1000° to 1200° Fahr., pressure of $3\frac{1}{2}$ to $4\frac{1}{2}$ lbs. on the square inch, using 6 tuyeres. It was blown in March, 1867, and in the year 1868 produced 25,327 tons of pig iron, and in February, 1869, was producing about 600 tons of foundry iron per week. The consumption of fuel is about one ton to the ton of pig iron; the ores are now 42 per cent., yielding 2 per cent. more than in smaller furnaces, for less goes into the slag or cinder than formerly with the small furnaces. The fuel is ordinary coke that could not be worked in small furnaces, owing to its injurious effect on the quality of the iron. The gas arrangements, or rather the arrangements for drawing it off, are so constructed that the supply is divided into 16 jets, or flues, so that each stove and boiler has its supply independent of the other, and there is enough for steam and for heating the blast. The flow of gas is regu-

lated with a facility equal to that experienced in the use of ordinary gas in a dwelling, the gas being consumed on the mechanical principle embraced in the argand burner.

The production of this furnace has exceeded the anticipations of the parties concerned by fully 50 per cent. As is illustrated in *Engineering** wherein it is stated that the furnace was expected to produce 400 tons per week, while it now produces about 600 tons. It is expected that it will keep in blast five to six years longer, or seven to nine years in all.

If it remains in blast for this length of time, it is probable that the expenses of repairs will be less than those of any other furnace, per ton of iron. There are *no repairs* charged to the Hot Blast *Stoves*, as owing to the principles of their construction it is supposed that none will be required.

The labor account of this furnace is but very little in excess of that of one of 18 feet bosh, whilst the product is double.

Estimate of cost of such a furnace at present wages and prices of materials, including furnace, casting house, engine house, lift, stoves, &c., complete to take the blast.

Foundations	\$ 5,300
Common bricklayer's work	24,800
Fire " "	37,500
Cast iron " "	25,000
Blast engine	13,000
Boilers, &c.	6,500
Pumps	2,500
Machinery for hoisting	3,500
Sheet iron work	4,000
Wrought iron bands	3,000
Valves, pipes, cocks, stays, &c.	5,500
Various expenses, such as fitting, setting engines, boilers, scaffolding, extra labor	15,000
	<hr/>
	\$145,600

Cost of producing iron on the Lehigh in this furnace—

* Aug. 10th, 1866, page 104.

Ore, to the ton of iron	. . .	\$11.00
Coal . . . . .	. . .	2.00
Limestone . . . . .	. . .	1.00
Interest, labor, and repairs	. . .	3.00
		<hr/>
		\$17.00

Common labor is estimated at \$1.50 per day.

The above estimate, sent us by Mr. James Henderson, engineer, whose computations are made for March, 1869, needs the emendations, Appendix H.

While this may be considered a "monster furnace," we have also accounts of the successful working of other furnaces in 1868, of much greater dimensions.* In the Cleveland (Eng.) district the largest furnaces in the world and most economical modes of working, are to be found. Three or four years ago the Acklam furnaces at Middlesborough, built by Mr. Beckton, were the largest ever constructed, being $22\frac{1}{2}$ feet in diameter at the boshes, and 70 feet high from the bottom of the hearth to the top of the brickwork; each are capable of holding 1250 tons of material, and turn out about 350 tons of iron per week. In these furnaces the angle of the boshes was much steeper than it had before been the practice to adopt, being 68° with the horizon, while one of the Ormsby furnaces, belonging to Messrs. Cochrane, has its boshes inclined as much as 75° . In the construction of blast furnaces, the amount of masonry employed, proportionate to the dimensions, has been much reduced. Instead of being constructed entirely of stone and brickwork, held together by iron hoops at intervals, the masonry is now frequently built up inside a malleable plate-iron jacket, which envelops it. The direct result of these large furnaces has been the effecting of very great economy. Instead of using 36 cwt. of Durham coke per ton of pig iron produced, there is now used 26 cwt., in some cases even less; whilst some of these produce one ton of pigs with 21 cwt. of coke from an argillaceous iron stone containing about 31 per cent. of iron.

* British Practical Mechanic's Magazine.

Messrs. Bolckon, Vaughn & Co. erected two furnaces characterized by their peculiar proportions of only 16 feet bosh and 95 feet height. These furnaces have worked well, and there has not been any difficulty in getting the blast to ascend through the materials, neither have the furnaces choked or "gobbled up" as was feared; and instead of consuming one ton of coal per ton of pig iron as formerly, for heating boilers, blast ovens, and calcining kilns, 10 cwt. suffices. The blast is now heated to a much higher temperature. A few years ago the maximum temperature employed was 500°; this has been gradually increased to 700°, 800°, 900°, and, quite recently, 1050° and 1100° Fahr., and the probabilities are that they will ere long employ much higher temperatures. A great point of this economy is attributable directly to the use of the blast furnace gases for firing the boilers and blast ovens, and much, no doubt, to an increased efficiency in management. The materials employed in the Acklam furnaces average about six tons to each ton of pig iron produced, the proportions of each being:—

	Tons.
Cleveland Ironstone,	3 50
Limestone,	0.75
Coke,	1.30
Coal (bituminous),	0.50
	<hr/> 6.05

or about 4.25 tons of raw materials independent of the fuel. Since the erection of the Acklam, as well as the Ormsby furnaces, and because of their economical working, dimensions have still further increased. Indeed in the Cleveland district, capacities, per furnace, of from 25,000 to 30,000 cubic feet are becoming the rule, the boshes of some furnaces at Stockton being as much as 26 feet in diameter; whilst the Ferry Hill and Rose-dale Company have erected a pair 27 feet in diameter, with a height as much as 102 feet. Unquestionably the iron-masters of this district have set a good example to those in Wales, Staffordshire, and Scotland; and the economy they have effected, by paying attention to true

principles in construction and practice, has been seriously felt in Glasgow by the great stagnation in the demand for Scotch iron, owing to the lower price at which the Cleveland masters are able and willing to supply the market, whilst they, too, labor under the disadvantage of having an inferior ore to deal with.

Up to the present time the largest of these high, or so called monster furnaces of which we have any account, is one of the Ferry Hill and Rosedale Iron Company at Ferry Hill and built by Mr. S. Faulkner, contractor, Coxhoe, the height of which is 105 feet and across the bosh 27 feet 6 inches. When full its total weight is 2 00 tons. The stoves and all other arrangement are said to be fitted up in a splendid manner.*

Lurmann's Improvement.

One of the latest and most decided improvements is found in Lurmann's furnace front. We will give what the inventor claims and, afterward, what has come under our personal observation.

This improved blast furnace has no tympanum, no forehearth, and no damstone; the hearth is closed in its entire circumference; the slag stands constantly at the same level, and therefore rests quietly in the hearth, and flows off *continually* at that level, through a cast-iron slag discharge-piece kept cool with water and introduced at any given point in the circumference of the hearth. The middle of this slag discharge-piece lies from six to eight inches below the middle of the tuyeres.

The aperture of the slag discharge is, in the centre, cylindrical, and widens conically towards either end, but most towards that end which leads into the hearth. In order to facilitate the fastening and changing of the discharge-piece, it terminates at the top in a swallow-tailed projection, by the aid of which it may be wedged tight to a plate which is attached over the part of the hearth selected for the slag discharge: it is kept cool

* London Mining Journal.

by water. The plate has also, at either side of the slag discharge-piece, hooks, under which an iron bar is laid to keep in the slag discharge-piece. The rear side of the slag discharge-piece is then flush with the inner surface of the hearth, or projects somewhat into the interior; and the intermediate space around is filled with fire-clay, sand, or earth. Since the end of the slag discharge-piece reaches into the hearth, and lies, therefore, as near as possible to the source of heat, it follows that, even if a furnace is working badly, it is much easier to make the slag flow in this way than when it is obliged to traverse the long road under the tympanum, through the fire-hearth and over the damstone.

This new arrangement claims to do away with the well-known inconveniences of the old one, as it will appear from the following summary of its advantages:—

1. The slag always flows off at the same level, thus avoiding fluctuation, or oscillations of the slag in the hearth, and consequent increased wear of the latter.

2. The interruptions caused by tapping and by cleaning the slag from the fire-hearth are entirely avoided. The loss occasioned by such stoppages is found by experience to be twice the work which the furnace would have done in the time covered by the stoppage.

3. Since no stoppage of blast, and, hence, no cooling takes place, the blast-furnace thus constructed is able to preserve a higher and more regular temperature.

4. By the abolition of the fire-hearth and damstone, it is possible to transfer the iron discharge to the wall of the hearth, and the opening of it becomes much easier, since it is four or five feet nearer the centre of the furnace.

5. The perfectly closed hearth at once allows a considerable increase of the pressure of the blast, since a blowing out of material is impossible.

6. This possibility of increasing the blast-pressure is important in all cases, and especially where crude coal (as, for instance, in the anthracite furnaces of the country), or dense charges are used. Under these circumstances, the improved furnace will show great gains in

the rapidity of successive charges, and consequent increase of production.

7. The number of workmen may be reduced by one-third, and, what is of higher importance, the degree of skill demanded is not so great as in the old furnaces. Fewer tools are required, and no fire-proof materials for repairs.

8. The length of campaigns is indefinitely increased.

The method of running such a furnace is briefly as follows :—

The slag discharge is not closed before tapping the iron, since the slag stops running of itself, when the iron begins. After tapping the iron the iron-discharge is plugged, and, during this time, the slag-discharge is stopped with a little sand or earth. The water used in cooling the discharge-piece is reduced to a minimum. The duration of this work is four or five minutes. The full allowable blast pressure is now applied, until the slag appears at the discharge, when the sand or earth is removed, and the workman thrusts a round bar through the opening and the slag crust behind it, into the liquid slag, and then quickly withdraws it, when the slag flows out in a stream. The flow of slag may be completely regulated by means of the water cooling the discharge-piece; since by strongly cooling the latter, the slag is "frozen" in the passage, reducing the size of the discharge, and *vice versa*. During this entire process, *the blast is not interrupted, nor its pressure diminished*. The size of the slag-discharge opening for a blast furnace depends on the consistency and quantity of the slag. For a large coke-blast furnace with thin slag, an inch and a quarter, and for a tougher, thicker slag, up to two and a half inches are employed.

No more work is done on the furnace until the next tapping for iron; and, above all, *the blast does not require to be interrupted for an instant*.

When an ordinary blast furnace works badly, that is, when from lack of the proper flux-mixture, or the requisite temperature, the slag cannot be made to flow freely, the fore-hearth is liable to become clogged, rendering it

necessary to draw off the slag, through, under, or near one of the tuyeres ; but such cases are more easily managed with the new arrangement, since, if the slag will not flow through the aperture of the discharge-piece, it can be drawn off without difficulty through the space surrounding the discharge-piece.

This new arrangement may be attached at any time, and in a few hours, to a furnace of the old form, *without interrupting its operation*. To do this, it is only necessary, after tapping, to replace the tympan plate with the cinder block plate, which is also cooled with water. This plate, with the slag-discharge, must be so placed that the latter shall lie at least six inches below the middle of the tuyeres, and its rear edge either project into the furnace, or be flush with the interior surface. This is not difficult, since an old furnace is, ordinarily, no longer very thick in the neighborhood of the tympan. The spaces between damstone and former tympan, and around the slag discharge-piece, are now filled up, and the work goes on regularly, as above described. The distance between the iron and the slag discharge, and the consequent number of charges between two tappings, are determined by tapping a few times, earlier than usual. These, therefore, are the claimed advantages, and the regulations as presented by the inventor.

Two of our most experienced iron-masters have introduced this improvement, and we have had the opportunity of examining its working for six or eight months; we, therefore, regard the invention as a decided improvement, and feel that some of the claims, as above presented, are properly founded. It is somewhat singular, however, that even after several months of successful working, we have found workmen who objected, or were very unwilling to give the innovation a welcome. At a new furnace on the Lehigh, of 18 ft. bosh, the iron tap hole is on the right of the breast, and the cinder block about 20 inches to the left, the iron-tapping hole not being back of the furnace, as recommended in the originator's plan. This is supposed to be more convenient than the substitution of an additional tuyere. The cost,

with the royalty for introduction, is about \$150 a foot of bosh.

An interesting suggestion was made in England, by Mr. Morgan Morgans, of Brendon Hills, who, in 1867,* patented a blast furnace with a central core and tuyeres, so that furnaces of considerably increased diameter might be built to work with a thorough penetration of blast, and, as is claimed, at a higher heat than in the usual form. Mr. Comber, the principal of the Bristol School of Mines, delivered a lecture there, upon the probable advantages of this furnace. Mr. Morgans proposes to adopt diameters as great as 32 feet, and he alleges that he would not only save in the proportionate radiating surface to the capacity of the furnace, but that by his higher heat he would extract more iron from the slag, and in various ways save upwards of 10s. [\$2.42] per ton of pigs.

This may not be in all respects a feasible plan, nor can we, in a work like the present, suggest that which would be; but there can be but little doubt that a central chamber receiving the hot blast, and distributing it through a large number of tuyeres, with less individual pressure, would be the most economical method of introducing the blast to the hearth of the furnace.

CHAPTER IV.

BUILDING, BLOWING IN, PRACTICAL REMARKS UPON THE MANAGEMENT.

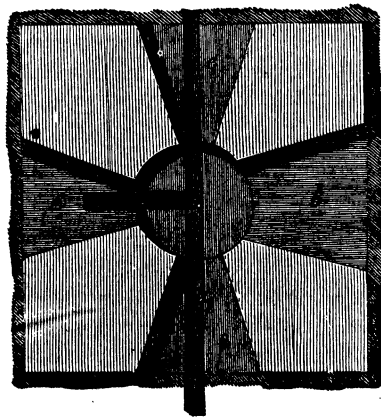
The Building of a Blast Furnace.

THE following remarks by Mr. Overman are important, and although made for 1845 are eminently useful and practical, when modified by the circumstance of the time when written:—

* Engineering.

[A furnace should be located on a dry spot, free from springs and water of any kind, and not exposed to floods after heavy rains. The ground should be then excavated, until the bottom is sufficiently solid to bear the heavy weight of the stack. The foundation should be at least one foot larger in each direction than the base of the furnace; that is to say, if the furnace is thirty feet at the base, the foundation ought to be thirty-two feet square. Any kind of hard, large stones may be used to fill the excavation. No mortar should be used in the stone work. We should be careful to leave some channels through which rain or spring water, in case it should penetrate the foundation, may flow off. Such a drain should be carefully walled up and covered. The cavities or channels for the blast pipes are to be placed level with the ground; and the four pillars of the furnace then laid out. Fig. 87 shows the arrangement of

Fig. 87.

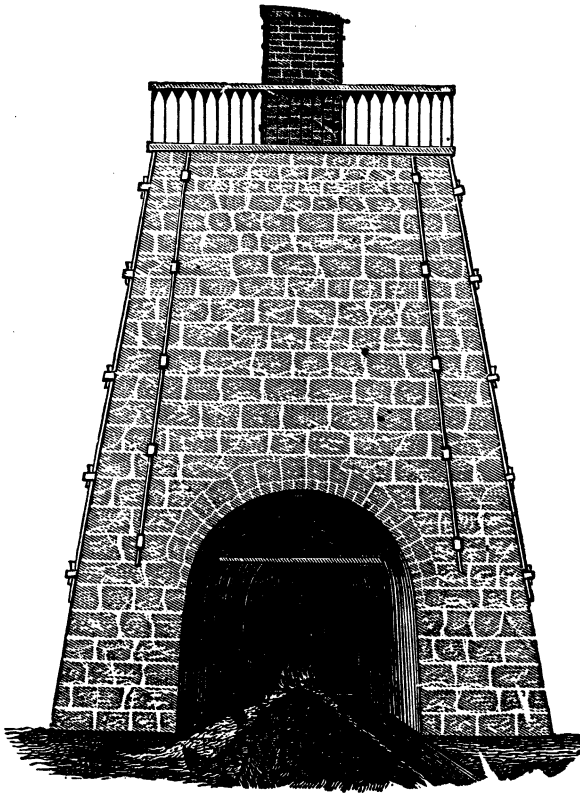


Ground-plan of the furnace foundation.

the pillars and that of the channels for the blast pipes *a, a*. If the stack is thirty feet at the base, the work arch *b* may be fourteen feet wide. Eight feet are thus left on each side of the pillars. The tuyere arches *c, c, c* measure ten feet, which leaves ten feet pillars. The size of the room in the centre is to correspond with the

diameter of the boshes; that is, nine and a half feet. This is to be measured from the centre of the stack by drawing a circle of four feet and three-quarters radius. The inside of the pillars is to be built plumb; on this the lining rests. The walls towards the arches should also be plumb; but the outside should be furled according to the general tapering of the stack. The height of this stack is thirty-five feet; its width is fifteen feet seven inches at the top, and thirty feet at the base, thus

Fig. 88.



Front view of a blast furnace.

leaving a slope of two and a half inches to the foot. The material of which a stack is built has but little in-

fluence in the operation in the furnace. Building stones of any kind, as granite, graywacke, sandstone, or even slate, will answer; but limestone is not adapted for this purpose. The pillars are to be built with great solidity, with good mortar, and may be raised to the place in which the arches are set. The arches are turned of brick, which ought to be hard-burned. Fig. 88 represents the work arch; this commences seven feet above the ground, and forms just the half of a circle. The arch, from fourteen feet at its outside, contracts to five feet at the tympanum.* The tuyere arches are but ten feet wide, and twelve feet high; they contract, towards the interior, to three feet. The binder *a* may be walled in at the height of ten feet, and of course crosses the arch. The stone work above the brick arches should be arched, that some of the pressure on the latter may be relieved. The brick arches have some advantage over other arrangements. Stone arches are very apt to crack and split; and if, as often happens, the blast works out at the tympanum or tuyeres, the stones crack and fly in such a manner that it is dangerous to go near the fire. Iron joists are very expensive; besides, by their expansion and contraction, they weaken the stack. The brick arch is very strong, safe, and durable. When the pillars all around are seven feet high, the arches may be commenced; also the rough-in-wall, which must be four feet wider than the lining at the widest part of the boshes, that is, thirteen feet and a half in diameter. This in-wall is to be carried to a height of five feet, plumb, whence the contraction commences. From this point to the top the contraction is uniform, and is $1\frac{7}{10}$ inch to the foot, thus leaving the top seven feet wide. The stone work above the arches, or the place at which the binders commence, ought to be very open. Care should be taken not to use too much mortar; besides, the mortar must not be strong, but should consist mostly of coarse sand and spalls,† or fragments of stones. Chan-

* Abbreviation of tympanum, a panel.

† From Old German *spellen*, to split; small chips of stone.

nels should be left, at such width that the binders may, at any time after the furnace is built, be pushed through them. These channels ought to be at least six inches wide; and from each a branch channel should lead in a radial line towards the interior. In this way they serve as drains for the watery vapors from the interior of the masonry.

When the rough walls are finished, the lining or in-wall is to be put in. This must be constructed of fire bricks; or where these cannot be obtained, or where they are too expensive, of fine-grained white sandstone, which stands the fire well, does not crack, and is an excellent material. Where the former are used, the work is very simple, for fire-bricks are moulded to the proper bevel. A long board or scantling, or a sapling, is cut of the proper length, reaching from the pillars to the top of the furnace, that is, twenty-eight feet. A round wooden pin is fastened on each end, on which this pole may be turned. Upon the pillars, as well as upon the top, a plank is fastened; in each of these planks, an auger hole just in the centre of the stack or lining is bored. The pole is set in the centre, and made to turn round its axis. To this pole some pieces of board may be fastened, in a radial direction, on which an upright, giving the proper bevel of the lining, is fixed. By turning the whole round its axis, the interior form of the in-wall is moulded. The mortar used in the lining should be fire-clay, mixed with some sand, or, what is better, with a little of the very fine riddlings from the ore yard; these riddlings make the clay very tough, and prevent its shrinking and crumbling. Fire-brick linings are undoubtedly preferable to stone linings; but they are more expensive. Where stones are used, they should be cut and dressed, according to bevel and circle, and laid in courses of equal thickness. The mortar to be used is the same as that just described. The lining should rest upon the pillars and arches; and, where stones are used, the last five feet at the top should be built of fire-brick. If fire-brick cannot be obtained, well-burnt common bricks, which do not shrink, and

which are not brittle, may be used. Between the lining and the rough wall, a space of eight inches is left, because the width of the fire-brick or stone wall seldom exceeds sixteen inches. This space is to be filled either with fragments of stone, or broken-furnace cinders, and at intervals of four or five feet may be covered with a layer of lime mortar, to prevent, in case a stone of the lining should give way, the penetration of the blast.

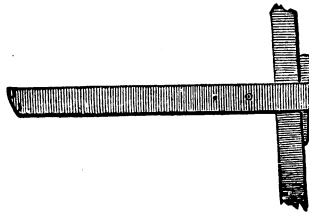
In the mean time, that is, while the lining is raised, the binders may be put in and secured. The strongest and most secure binders are wrought-iron bars, three inches wide, and three-fourths of an inch thick. They can be rolled in one length, and should be two feet longer than the actual length across the stack; each end of such a binder is to be bent round to form an eye, as shown in Fig. 89. A flat bar of the same dimensions as the binder is pushed through this eye; and sufficient room is left for a key or wedge, as shown in Fig. 90.

Fig. 89.



Eye of a binder.

Fig. 90.



End and key of a binder.

To protect this end of the bar against burning, in the blacksmith's fire, the eye is formed by simply bending the bar round, and by riveting it in two places. A slight welding heat may be applied to the joint. There should be five binders on each side of the furnace, making twenty binders in all; as well as eight bars reaching from the top to the lowest binder, as shown in Fig. 88. The top of the stack should be covered with a cast-iron circular plate, as wide inside as the lining, and about twenty-four inches broad; this plate should be large enough to cover the lining and space, as well as a

small part of the rough wall. It is advisable to cast this plate in halves; for if in one piece, it will warp and crack, and thus disturb the tunnel head chimney which is to be put upon it. Upon this plate it was usual to build the chimney seen in Figs. 89 and 90. This chimney was commonly square, because this form is better adapted for binding; the inside should be as wide as the top of the furnace, and its height from ten to twelve feet. On one side, a square opening is left, for filling the furnace; this opening must be secured by an iron door, which is shut after every charge. Many objections have been raised against these chimneys, and much has been said in their favor. An objection against them is, that a careless filler will throw the stock, and particularly the ore and limestone, mostly towards the door; by this means the ore is brought to the back of the hearth; the result is bad work. Another objection is, that the fillers are very apt to be negligent, because the stock is not easily thrown in, and because great attention is required in levelling it. These disadvantages are merely imaginary, and regularity and order will overcome them.

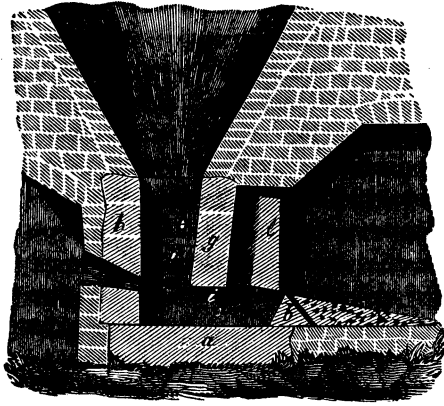
The advantages, however, are of a highly important character, and deserve our attention. These chimneys, if properly managed, maintain a uniform temperature at the top; and it is in the power of the manager to regulate the warmth of the top, by simply attending to the opening or shutting of the door. To be able to lower or raise the temperature is very convenient, because some ores bear a high heat at the top, while to others a high heat is injurious. Another advantage is, that, in any kind of weather, the flame is not troublesome to the filler. These chimneys are built and secured by binders similar to those used in the stacks of puddling furnaces, which will be shown hereafter.

The construction of the hearth is the business in which the iron master himself takes an active part. Still, as this is governed by general rules, we shall give a statement, sufficient to serve our present purpose, of the principles by which we should be guided. It is a mistaken

notion that every sandstone which resists fire will make good hearthstone. It is not the heat which destroys the hearth, but the chemical action of the materials in the furnace. The durability of a hearth is determined by the skill of the manager. Any refractory material constitutes a good hearthstone, particularly silex, clay, and some modifications of lime; but a mixture of these three substances must not be applied. The form of aggregation has considerable influence; but of this we shall speak hereafter. Sandstones are sometimes used in this country, while in other countries, the material varies according to the nature of the ore and fuel. Lime-stone, sandstone, gneiss, granite, plastic clay, or fire-clay is employed, as circumstances require. But sandstone will answer in all cases, if the ore and fuel are properly prepared. Any sandstone which is free from iron, or from lime, or from matter which towards silex acts as a strong alkali, may be used for hearthstones. Its refractory quality must be proved by some previous test. This test consists in drying a fragment of the rock in question by a very low heat on the top of a stove, or near a fire grate, for twelve or twenty-four hours; and then exposing it to the gradual heat of a blacksmith's fire. If the stone is friable, after a good red or white heat, or if it fall to pieces by being moistened with water, we may conclude that the rock contains lime, and that it is not good for hearthstones. But if the fragment resists the first heat well, and if it is still hard and compact, we may expose it to a welding heat in the blacksmith's fire, urging the bellows strongly for half or three-quarters of an hour. If the stone resist this heat, and if its color is not altered to brown, we may conclude that it is perfectly safe to construct a hearth of it. Some specimens assume a reddish hue; but we must not thence infer that their nature is not refractory. When heated in the blacksmith's fire, the fragment becomes glazed; this glazing is produced by the fuel. Stonecoal occasions a black, and charcoal a white glaze: the former is the result of sulphate of iron; the latter of the alkalies of the wood ashes.

Fig. 91 shows the method by which hearthstones are commonly prepared and arranged. *a* is the bottom stone, made of a fine cross-grained sandstone; it is from twelve to fifteen inches thick; at least four feet wide, and six

Fig. 91.



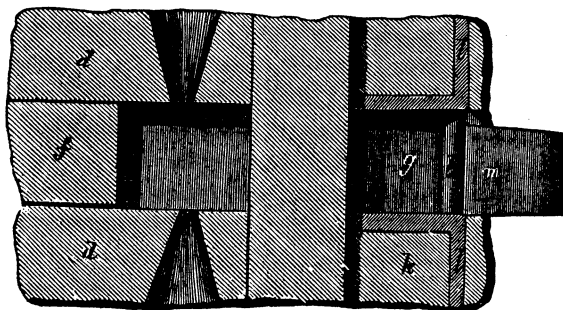
Section of a blast furnace hearth through the damstone.

feet long; it reaches underneath at least half of the damstone *b*. This bottom stone is well bedded in fire-clay, mixed with three-fourths sand. If possible, the transverse section of the stratification ought to correspond with its upper and lower surface; that is, if the stratification, in its native position, is horizontal, it here ought to be vertical. This arrangement affords the advantage of saving the bottom, of keeping it smooth, and of lessening its liability to injury. After the bottom stone is placed, the upper part of which must be three-fourths of an inch lower at the damstone than at the back, the two sidestones *c* are laid, imbedded in fire-clay. These stones must be at least six feet and a half long, reaching from eighteen inches behind the crucible to the middle of the damstone. Their form is commonly square, that is, a prism of four rectangular sides: if the tuyeres are eighteen inches from the bottom, the stone is eighteen inches high and eighteen inches wide: if twenty inches from the bottom, the stone is twenty inches on each side. The transverse section of the grain

is placed towards the fire, which must be the case with all the hearthstones. The sidestones are sometimes perpendicular to the bottom ; but they are often bevelled according to the slope of the hearth. Upon these stones the tuyere stones *d* are bedded ; the latter suffer much from heat, and, therefore, ought to be of the best quality. They should be from twenty to twenty-four inches square ; and even larger dimensions would be advantageous. The tuyere holes *f*, a kind of tapered arch, are to be cut out before the stones are bedded. These stones do not reach farther than to the front or tympestone *g*, and are, therefore, scarcely four feet long. The topstone *e*, of no particular size, is generally sufficiently high to raise at once the crucible to its designed height. After both sides are finished, the backstone *h* is put in, which, in case three tuyeres are used, is an almost cubical block ; but where only one tuyere, or two opposite each other, are used, this backstone is frequently made sufficiently large to reach from the bottom to the top of the crucible. The tympestone *g* is then put in its place ; this stone is from four to five feet in length, so as to overlap both side tuyere stones ; it should be of good quality. The tympestone is generally raised from three to four, sometimes even six or seven inches above the tuyere, by putting at *i*, on both sides of the sidestones, a small block of sandstone, or, what is better, fire-brick. The raising of the tympestone has this advantage. In cases of difficulty, and of hard work in the furnace, the keeper is enabled to reach with a crowbar above the tuyere. Where argillaceous or clay ores of gray iron are smelted, this is necessary. The opening left by raising the tympestone is easily kept tight by a good stopper ; for this purpose, a flanch, which reaches under the stone, is cast to the tympestone-plate *k*. The tympestone is protected by the tympestone-plate, which must be two inches thick, imbedded in fire-clay, and secured by two uprights *l*. These angular iron plates protect the stones or bricks on each side of the tympestone ; they are more distinctly shown in Fig. 92. Besides holding the tympestone-plate, they afford the advantage of keeping the forehearth clean ; for the hot cinders will

not adhere to the iron plates, but are very apt to stick tenaciously to stones or brick. At this stage of our work

Fig. 92.



Horizontal section of a furnace hearth through the tuyeres.

—during the whole of which great care must be taken to form good joints, and to employ good refractory mortar, that is, fire-clay mixed with river quartz sand, or, what is preferable, with sand from pounded furnace cinders—the boshes may be built in. In charcoal furnaces, if steep, these are generally made of fire-brick, but if built at an angle of less than 50° , good sand, mixed with a little fire-clay, is an excellent material. In the latter case, the mixture should be well stirred and worked, and every pains should be taken that the compound is well prepared before it is used. It should be well pounded in, and, to prevent cracking, should be gradually dried. If fire-bricks are used, made in proper form, and of the largest possible size, there will be no difficulty in putting in good boshes. The damstone *b* is very seldom laid in its place, before the furnace is properly dried, and ready for the blast. In protecting plate *m*, the dam plate, can be laid at any time after the furnace is in operation.

The space between the hearthstones and the rough wall of the furnace stack,* is filled and walled up with

* From German *stecken*, a pile or heap, and applied to any chimney attached to furnace or locomotive.

common brick or stones; the former are preferable, because they are softer, and have less tendency to move the rough wall, by the expansion of the hearthstones.

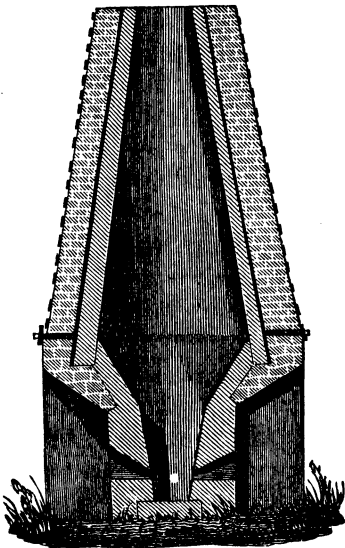
The expense of building a stack of the foregoing size varies according to locality, and to the facilities we have at our command.

(The following estimates were supposed to be correct in 1850): The rough stonework of the foundation will amount, at twenty-four and three-quarters cubic feet to the perch, to 200 perches. This foundation may be laid at twenty cents a perch. If stones can be quarried and hauled to the spot at forty cents, as is generally the case, the stonework may be laid at a cost of one hundred and twenty dollars. The excavation, estimating the expense of removing one cubic yard of earth at fifteen cents, will cost twenty-four dollars and seventy-five cents. The expense of the rough wall, assuming it to contain nearly 600 perches, will be one dollar a perch; if stones are included, one dollar and forty cents. Masons, at that price, will make a smooth, if not a hewn, outside. An in-wall of stones will cost nearly 100 dollars; one of fire-brick, 350 dollars. The cost of hearth and boshes may be calculated at 150 dollars, if the latter are of fire-brick; but if of sand, at 100 dollars—provided, of course, that the materials are close at hand. Binders, tymphplate, dam-plate, and chimney binders at the top, will cost 350 dollars. Therefore, a stack of the size stated may be assumed to cost, on an average, from 1300 to 1600 dollars.

Furnace stacks may be built more cheaply with bricks than with stones, where bricks can be made and laid at a reasonable cost. The rough walls of such brick stacks are generally not so thick as those of stone; but, even though they were, they would not be more expensive than stone, if a thousand can be laid at four dollars; and this may be done without much difficulty. Furnace stacks of brick have been built at various places; and their form above the boshes is generally round; they are then called cupola furnaces, from their resemblance to the cupola of the foundry. The Great Western Iron

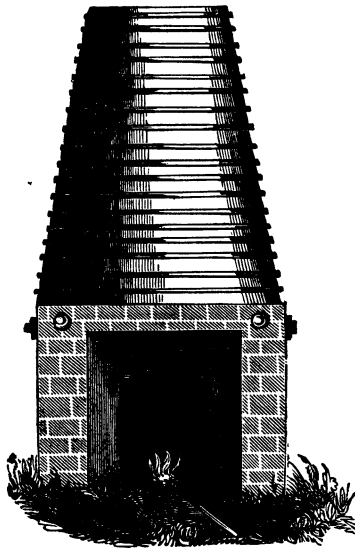
Works, in Western Pennsylvania, erected two such stacks; but these are partly built of stone, that is, the lower or square part beginning at the ground, and terminating at the work and the tuyere arches. This kind of furnace does not bear a high reputation in Europe. We observed them in England and France, where the general complaint against them is, that they work irregularly and consume a greater amount of fuel than square stacks. The cause of these evils may have been too thin and too rough walls, which may easily be avoided. But these furnaces have another disadvantage, that is, they nearly always break the strongest binders. In addition to this, they require too many binders; so that, on an

Fig. 93.



Section and interior of a cupola blast furnace.

Fig. 94.



Front view of a cupola blast furnace, at the Great Western Works.

average, a round stack is not cheaper than the square stack. There may be instances, some of which we shall produce hereafter, in which a round stack is preferable. Still, for the sake of those who may be disposed to build

a round stack, we will present a drawing of one in operation at the Great Western Works.*

Fig. 93 represents a vertical cross section, and Fig. 94 a front view, of a cupola furnace built of brick. The drawing is so distinct as to need no particular description. The whole stack can be built altogether of brick; or partly of brick and partly of stones, as is the case at the Western Works; or altogether of stone. Stone, however, would be very expensive, on account of the dressing necessarily required. Through the lower or square part, four binders are laid; the hoops, of wrought iron of good fibrous quality, of the upper or round part, must not be more than six inches apart, and should be two inches wide, and three-fourths of an inch thick. Below each hoop the last layer of bricks projects at least half an inch; upon this layer the hoop rests. If the stack is built of stones, pieces of iron bars are walled in to support the hoops. Between these hoops are left air-holes, through which moisture has vent.

Blowing in a Furnace.

When a furnace is erected and ready to be fired, a small fire may be put in the hearth. We should always be cautious to give the interior of the hearth a lining of common brick. This will prevent, in a great measure, the cracking and scaling of the hearth-stones. The fire is fed from below. Any kind of fuel will serve for this purpose, because the fire is only designed to dry the masonry. If the stack is new, or if it is one which has been for a long time unused, it is necessary to cover the throat by iron plates, and to leave but a small hole; this hole may be so regulated that we may burn just as much fuel as we choose. Seven weeks, and if the season is cold, eight or ten weeks of constant firing are considered necessary to dry a new stack, so that it can be charged with charcoal. But before the furnace is charged, the

* Brady's Bend, Armstrong Co., Pa., situated on the Alleghany River.

temporary lining or brick in the hearth must be removed. The lower part of the furnace, or the hearth, is to be filled gradually, and the fire must be permitted to rise in a blue flame on the top of the coal before the furnace is filled higher than the boshes. From this point half coal and half brands are to be used; the latter addition causes a more liberal draft of air in the furnace. If the furnace is quite warm before putting the charcoal in, and if we are confident that no moisture exists in the masonry, ore may be charged after the furnace is half filled with charcoal; but if we doubt that moisture is wholly expelled, the whole stack should be filled with coal, and the fire kept up until we are satisfied that the walls are perfectly dry. Where everything is ready for the start, repeated grates may be formed to facilitate the burning of coal, as well as to heat the furnace. Grates are formed by laying across the tump a short iron bar, as high up as the damstone; by resting upon this bar six or seven other bars, or ringers (crowbars), and by pushing their points against the backstone of the hearth. A grate thus formed increases draft and heat to a considerable degree, and very soon brings the top charges down into the hearth. Where ore is charged to the top, the descent can be accelerated by leaving the grate most of the time in the hearth; but care should be taken that too much coal does not remain at the bottom, for this will injure the bars. In this way the ore charges may be brought down within twenty-four or thirty hours. But if we are not to put the blast in, and to commence smelting, the descent of the ore charges may be delayed three, even four days, without any injury to the following operations; when everything is in order, the sinking of the ore may be hastened. This will be indicated by melting drops, often drops of iron, before the tuyeres. When these are seen, the damstone is to be laid, imbedded in clay; also its protector, the cinder platem. The hearth is once more cleaned; the hot coal then drawn towards the dam, and covered with moist coal dust; after which a gentle blast may be let into the furnace. During the first twenty-four hours, but little iron is made;

most of the ore is transformed into slag; and the iron which comes down gets cold on the bottom stone, where it is retained. At this early stage, it would not be prudent to urge the blast machine too fast, for great caution is required to prevent those troubles which result from a cold furnace. These troubles are, generally, cold iron in the bottom, and, in consequence of that, cold tuyeres. Gentle blast, small burden, and great attention alone will prevent these evils. Where a furnace has been for a week in blast, having in that time produced from nine to ten tons of metal, and where the hearth is clean, that is, where it is perfectly free from cold iron, or clinkers, the burden may be increased, and the blast urged more strongly. A well-regulated furnace will, during the second week, make from sixteen to eighteen tons; and the same amount during the third and fourth weeks. A furnace, just started, should not receive so heavy a burden of ore as a furnace which has for some time been in operation. About half the regular burden should, as a general rule, be taken; that is, if a full charge of ore is assumed to be 700 pounds, the starting charge should be 350 pounds. This amount should not be increased for at least three or four days, or one week. During this time, while the light charges last, an abundance of brands along with the coal may be used for the purpose of keeping a clean, open furnace.

Practical Remarks.

Inasmuch as charcoal furnaces are yet numerous in some parts of the United States; and inasmuch as they exhibit peculiarities which cannot appropriately be considered under the general head of blast furnaces, we shall take a separate survey of their management.

The erection of a charcoal blast furnace in a new locality is a precarious undertaking; and that losses, in case of failure, should not fall heavily, the utmost economy should be observed. Failure depends not so much on the material used, as upon other circumstances at times beyond our control. In a new locality, few, if any,

roads lead to the site of the furnace; or at least, they are seldom in a condition suitable for our purposes. This item often absorbs more means and time than one can well conceive. In new localities, the proprietor is compelled to open and improve almost every foot of the roads which lead from the coalings to the furnace, as well as the roads which lead to and from the ore banks. The dead work in mining operations should be well considered before we venture upon the erection of a furnace, for this item may augment the expenses of a new establishment to a degree which the business is unable to bear. In addition to this, no stack should be built, no improvements of any nature should be made, before the price of the ore at the furnace is well settled.

A furnace stack is not so important an object as it is frequently represented to be. Its interior, to be sure, must be carefully constructed; but its exterior has no influence whatever on the quality and quantity of the product manufactured. Furnaces of a very rude form are in operation in the Western States; and, though they are bound and kept together by wooden logs, they answer the purpose of their erection as efficiently as the finest stack built of hewn stones or bricks. In Sweden and Russia, where good masons are not generally found, many furnace stacks are but a pile of stones, rudely put together, supported by wooden binders. In building a furnace stack, the main object should be to secure a dry foundation, and dry, rough walls. If water can penetrate below the bottom stone, and keep that cool by evaporation, no advantages, however favorable, will make a furnace work well. The iron at the bottom may not only chill, but if, by an excess of fuel, it is kept liquid, it will be almost always white, and of inferior quality. Irregularities will thus be occasioned for which we are unable to assign any reasonable cause. A cold or wet bottom stone occasions more perplexity than any other imperfection in a furnace stack. If rough stones without any mortar are used, no channel for conducting the moisture from the interior is needed.

The construction of the interior has great influence

upon the operations of the furnace. The iron furnaces of Europe are governed, to a greater degree, by the nature of the ore than the furnaces of this country. The European works are mostly based upon spathic and magnetic ores; hence a difference in the construction of the furnaces is necessary. Nine-tenths of our ores are hydrated oxides of iron, and therefore a somewhat uniform shape of the interior of the furnaces is admissible. The form of the interior depends upon the kind of ore to be smelted; upon the kind of charcoal to be used, whether that from soft, or that from hard wood; and upon the kind of metal we wish to produce.

The height of a furnace stack has some influence upon the quality of iron obtained, but it has still greater influence upon the consumption of the stock, or raw material. Thirty-five or thirty-six feet is, according to our experience, the most favorable height. Stacks below this standard consume too much fuel; those which exceed it are worked with trouble, particularly if the coal and ore are small, for small coal and ore impair the draft. If we wish to enlarge the capacity of a furnace, it is better to widen the in-wall, that is, to increase the diameter of the boshes, or curve the vertical section, in such a way as to give the desired effect. But, if the charcoal is coarse, and the ore not soft and earthy, but in pieces, a stack forty feet in height will be found very advantageous. Where small coal and soft ore are used, the stack should be of less height. The shape of the in-wall has considerable influence upon the quantity and quality of the product. Where gray iron is desired, a hearth of at least five and a half or six feet in height, boshes at an inclination of about 60° , and a sufficiently wide throat, are needed. A narrow and high hearth will make gray iron very readily; but it is in many cases unprofitable. By using but one tuyere, a width of twenty inches between the tuyere and the opposite hearthstone will be found sufficient. By using two opposite tuyeres, a space of twenty-four inches between them may be considered narrow.

The throat or tunnel head of a furnace requires our

closest attention, because it mainly regulates the quantity of coal consumed. Upon this subject, the managers of furnaces differ in opinion; but the majority are in favor of narrow throats. We shall have an opportunity hereafter to speak more at length on this subject; at this place, we merely wish to draw attention to it. Experience unequivocally proves that narrow tops consume more coal than wide tops; still, the majority of our iron smelters, particularly in Pennsylvania, and throughout the whole West, adhere to the old narrow throat. That the western furnaces are not conducted so advantageously as they might be conducted, is clearly proved by the unnecessary amount of fuel they consume. The ores throughout the whole Western States are of such a nature as to facilitate the saving of fuel. Most of these ores are very porous, hydrated oxides. But from Berks County, Pennsylvania, to Hanging Rock, in Ohio, to say nothing of Kentucky and Tennessee, there is scarcely a furnace which uses less than from 160 to 180 bushels of charcoal to one ton of iron. Very few of them use a less, while a great many use a greater amount. There must be a cause for this waste of fuel; for waste it is, inasmuch as furnaces in the State of New York, and further east, consume but from 120 to 130 bushels to one ton, under circumstances less favorable, so far as ore is concerned, than these establishments enjoy. It may be partly accounted for by the fact that most of the furnaces are worked beyond their capacity; that is, a furnace which readily produces from thirty-five to forty tons per week, is made to produce fifty or sixty tons. This large amount of iron draws heavily upon the coal consumed; nevertheless, this circumstance only partially accounts for the quantity of coal wasted. Without entering into an extensive speculation on this subject, it will be evident to any reflecting mind that a throat of nineteen or twenty inches diameter, working upon a diameter of ten feet in the boshes, is very apt to press the largest quantity of coal towards the lining; that the ore, mixed with scarcely any coal, will descend into the hearth in almost the same state in which it was put in the furnace; that

here the whole reviving process is to be performed; and that part of the furnace above the hearth is, if not entirely, at least to a great extent, useless—for the hot gas, or blast from the hearth, will play through the loose coal along the in-wall, and, scarcely touching the ore, will pass up to the throat, where, to be sure, it performs some service, though this is of short duration. Such furnaces, with extremely narrow tops, we frequently meet, and never fail to find them good customers of coal. We do not wish to play the reformer in this matter, for we well know how difficult it is to eradicate an established prejudice, or even an opinion, among workmen at the iron manufacturing establishments; but by widening the furnace tops gradually, we may, by approximation, arrive at the improvement which appears to be so much dreaded by founders.

No attention should be spared to economize fuel; for the saving of fuel benefits everybody—the workmen, the master, and the public. How much can be accomplished in this way, may be learned from the fact, as we shall hereafter more fully show, that the amount of fuel used in charcoal furnaces, where other things are equal, ranges from 100 bushels per ton of iron to 300 bushels per ton; and that reductions in the use of fuel, by scientific improvements, may be accomplished in spite of local disadvantages. Our western furnaces, however, enjoy local advantages, so far as ore and coal are concerned, which ought to enable them to compete against the world in the manufacture of charcoal pig.

A furnace may be worked in relation to considerations of an economical, as well as to those of a mercantile nature. When the iron market is dull; when prices are low, and business is not hurried, experiments in relation to economy may be tried; but when the market is encouraging, and prices are high, it would be folly to disturb the progress of an active business, with the object of merely saving a few bushels of coal, or of slightly augmenting the price of ore. In the Western States, business has been so prosperous, that but little time for

making those economical improvements which we conceive to be necessary, has been afforded.

Blast, is a subject which does not deserve the importance which has been attached to it. If the blast machine is so constructed that it can furnish, at any time, without fail, 2000 cubic feet of air of one pound pressure per minute, blast presents no difficulty. In every case, iron bellows or cylinders should be erected. The motive power may be either a steam-engine or a water-fall. Wood is troublesome, requires constant care, and never produces that constant and regular blast which is so essential to success. Weak blast is frequently the cause of a failure in business. Where everything about a furnace is imperfect, an imperfect blast machine renders success impossible; nor, in fact, is success possible with one that is imperfect, where everything else is right. Therefore, a good blast machine is the first requisite at a furnace. Fortunately, we have this matter perfectly in our power, and we do ourselves serious injury if we fail to avail ourselves of it. In this instance, we know positively what to do—what, in fact, is needed. But if, in our misdirected zeal to save expenses, we put up an imperfect blast machine, we shall find that every dollar saved will be counterbalanced one hundredfold by losses in the furnace.

The application of blast in the furnace deserves investigation in every instance. We will notice some leading points; but these are not presented as infallible rules. Soft and weak charcoal cannot bear strong blast, and a pressure of from half a pound to five-eighths of a pound to a square inch, may be considered sufficient; strong blast would be likely to choke the furnace above the tuyere, by depositing charcoal dust in the boshes. Strong, coarse charcoal will bear a pressure of from three-quarters of a pound to one pound. A weaker blast is very apt to be troublesome, besides using more coal, and producing white metal. Ore, considered as an oxide of iron, free from foreign matter, has no relation whatever to the quality of the blast; but it is different with ore considered as a mixture of oxide of iron and foreign

matter. The kind of blast that should be applied depends very much on the fusibility of the foreign matter. But this question we shall discuss in another place. The form of the interior of the blast furnace is of considerable importance. A high, narrow hearth requires stronger blast than a furnace without a hearth, or a furnace with a low hearth; but the width of the top, in proportion to the diameter of the boshes, is of more importance than the quality or pressure of the blast. It may be laid down as a rule, that the larger the throat, in proportion to the boshes, the stronger ought to be the blast; and that a narrow top and wide boshes, while they permit a weaker blast, involve the loss of much fuel.

The air introduced by the blast machine into the furnace should be as dry as possible. The main reason that blast furnaces do not work so well during summer and clear, warm weather, as during winter, and cold, rainy days in summer, is, that a large amount of watery vapors is mixed with the atmospheric air in hot weather. This water is very injurious in a furnace, as we shall hereafter see. To keep the air dry, the blast machine should be erected at the coldest and driest spot we can possibly select. We should take especial care that it is not exposed to the hot air around the furnace, and that it is beyond the reach of the steam-engine; for the air will be more moist around the engine and the heated furnace than anywhere else. The best means of making a furnace work well during summer would be to put the blast machine in an ice-cellar.

With charcoal hot blast may be, under some circumstances, advantageous; but in others, it is decidedly injurious. It is, at best, a questionable improvement; and it may be doubted whether the manufacture of bar iron has derived any benefit from it; qualitatively, it has not. Hot blast is quite a help to imperfect workmen. It melts refractory ores, and delivers good foundry metal with facility. The furnace should be carried on for three or four weeks with cold blast, that the hearth and lining

should be heated thoroughly before the application of hot air.

The quantity of air required to be blown into a stack depends on the quantity of metal produced in the furnace. But there is a limit to the amount which the furnace produces; if we attempt to exceed that limit, loss, instead of gain, is the consequence. A narrow top, high stack, soft coal, and imperfectly roasted ores, require quantitatively more blast than where opposite conditions exist; but the blast must be weak. A wide throat, low stack, hard coal, and ores well roasted, require stronger pressure but a less volume of blast. The changing of nozzles and tuyeres is, therefore, a matter of considerable importance, and the effect of this change should be clearly appreciated before it is attempted.

The manner in which stock should be hoisted and delivered at the tunnel head, is a question of economy. If the digging of a yard is very expensive, and if the cost of stone walls and a tunnel head bridge cannot well be borne, coal and ore may be hoisted on an inclined plane, by means of the blast-engine, or by water or horse power. But, under all circumstances, there should be a bridge house, sufficiently large to receive the night stock, and where possible, also the Sunday's stock. To the coal and ore yard the manager should pay particular attention. The coal, after being unloaded, must, in every case, be left twenty-four hours in the yard before it is stacked in the coal houses, for it very often happens that coal will rekindle, even though two or three days have elapsed since it was drawn from the pits. Soft and bad coal should be mixed with the old stock, and immediately used; it is useless to store soft coal, for it will crumble to dust. Braise,* which is not used for the burning of ore, or at the tymp, must be saved, for it is an excellent fuel for the burning of lime. Iron rakes, for drawing coal, are commonly in use; but they are very destructive to charcoal, and should be avoided in the yard. Wooden rakes are preferable. Charcoal exposed to the influence

* Half burned brands.

of the weather during the summer season suffers but little in quality; but snow and frost are very injurious. If we expect good work in the furnace, all the coal must be stored under roof before frost sets in.

At a charcoal furnace, particularly where the stacks are small, great attention is to be paid to the roasting, breaking, and cleaning of the ore. Iron is revived with difficulty from imperfectly roasted ores, especially if the stacks are low, or of small capacity. In this case, the ore arrives at the tuyere in an unprepared state. The hearth is thus left to do the most of the work; but this it is unable to do; the consequence is that, even from ores of good quality, bad, or at least white, iron of inferior quality, waste of stock, and frequent disturbance in the regular work, will be the result. From low stacks, and from small stacks, we cannot expect anything like fair work, unless the ores are well roasted. Well-roasted ores are of a red or brown color; they adhere like dry clay to the tongue, and are easily broken. When ores are roasted so hard as to melt into a clinker, they are as bad as though they were not roasted at all; in fact, they may be considered worse, for such ores cannot fail to work badly; while raw ores can frequently be used with but little injury. The breaking of ores is a matter of great importance: ore that is too coarse is injurious; under some circumstances, so is coal that is too fine. A narrow top will work to greater advantage with small, than with coarse ores; and a wide throat requires uniform ore of not too small a size. This rule holds good in all cases. Experience has clearly proved that loose, soft, mouldy, and small ores do not work so well in a furnace with a wide top, as in a furnace with a narrow top; and the reverse is the case with hard, solid, and dry ores, such as the specular, magnetic, and spathic kind. If the ores are brought in a clean state to the yard, and if the roasting is done by wood and small charcoal, but little cleaning is needed; but if brought in an unclean state, and if any mineral coal is used for roasting, they should be carefully cleaned from the adhering dust. In every instance, a careful roasting of the ores at charcoal

furnaces will prove advantageous; this is the surest means of saving coal and blast, and of avoiding many annoyances in the working of the furnace. Even if we are not particular as to the quality of the metal; even if we are satisfied with white or mottled iron, the advantages of well roasted ores are so great, economically considered, that too much attention cannot be paid to this branch of the yard operations.

Of fluxes, and the mixing of different kinds of ore, we shall speak at the close of the chapter. But as this is a subject of the greatest importance; as on this depend the well-being and success of blast furnace operations, it will not be inappropriate in this place to call the attention of the furnace manager to it. The application of proper fluxes, or the mixing of ores and fluxes, is not only the basis of success, but by this branch of the manager's duty the quality and the price of the metal are determined. It has been proved by experience that the great difference in the amount of fuel consumed, varying from one hundred bushels to three and even four hundred bushels of charcoal to the ton of iron, chiefly depends upon the composition of the cinders or slag: besides this, the quality of the metal is regularly improved by applying the proper fluxes. Some previous knowledge of the elements of chemistry is required to enable one fully to understand this subject; but we shall endeavor to make it comprehensible, without employing scientific terms or technical phrases.

The working of a charcoal furnace is not difficult, if coal, ore, blast, and stack are in good order. The first cast, after starting a furnace, is generally taken on the second or third day; it is advisable not to tap too soon, for there is little or no danger in delay. A well-filled crucible for the first cast removes all the adhering cold clinkers in the lower parts of the hearth; heats the hearth thoroughly; and gives a fair chance, even good prospects, to the following casts. If, however, the bottom is too cold, so that the iron congeals on touching it, we should be cautious not to let too much iron accumulate in the hearth; but we should tap frequently, and make

every effort to produce gray iron, by which alone cold iron, sticking in the bottom, will be removed. If the hearth is cold, if the ores are too refractory, or if, through other circumstances, clinkers or cold cinders accumulate in the hearth, the furnace should be frequently opened, and these obstructions removed. This object, however, should be effected with expedition; otherwise, the withdrawal of the blast will leave the hearth too cool. If cold lumps of cinder are allowed to accumulate, they will by degrees reach above the tuyeres, and thus the furnace operations will be exposed to the greatest danger; for, if no coal intervenes between these cinders and the blast, the hearth is very soon cooled to such a degree that the descending iron and cinder, thus rapidly increasing, would finally bring the operation to an entire close, and compel a scraping of the materials out of the furnace. If strange or very refractory ores are to be smelted, it is advisable to lay the tuyeres six or seven inches above the tymptone, that the keeper may be enabled to reach with ease above them, and remove any obstructions which may there accumulate. The space between the dam and tymptone is very easily kept tight by a good stopper made of common clay mixed with sand. The burning out of a tymptone is a very disagreeable occurrence. To prevent this, various means have been devised. We shall allude to one, that which is commonly called the water-tymptone. This is a cast-iron pipe, six or seven inches square, with a round bore of from one and a half to two inches in diameter. This tymptone is laid across the forehearth, below the tymptone, and kept cool by a constant current of cold water. This is a very convenient method of saving the tymptone, and of preventing the stopper from being blown out; but it has several disadvantages. It keeps the hearth cool, and, what is a still greater disadvantage, it tends to chill the cinders of refractory ores; these cinders, when cooled, accumulate so fast, that they frequently compromise the safety of the furnace operations. We have tried this experiment, and have found it to answer exceedingly well where ores, well fluxed, were smelted; but we have found it accompanied with

difficulty and danger where—in addition to the presence of a strong cinder—strong iron, inclined to white, was manufactured. Where bog ores are smelted, and where a wide hearth is in use, we would recommend the watertyp; but in scarcely any other case will it afford any advantage.

The Management of Blast Furnaces.

We have alluded to the practical management of blast furnaces; but in this place we shall examine the subject more extensively. After the rough walls of a furnace are completed, the lining and hearth are to be put in. Of the geometrical form of the hearth and in-wall we shall speak in another place, and at present confine our attention to the material of which they are made.

a. The knowledge of the chemical composition of the material of a lining is of little consequence to the manipulations, and to the results of the smelting process. A material sufficiently refractory to resist a moderate heat, but of such an aggregate form as to permit of frequent changes in temperature, is all that is needed. Of all the known native and artificial materials, none answers better than a well-made fire-brick. Where fire-bricks are very expensive, or where they cannot easily be procured, a stone in-wall may be put in; but the application of stone is restricted to charcoal furnaces, where well-roasted ores and high stacks are employed. In no other case can a stone or slate lining answer the purposes of a good in-wall; and even where employed through necessity, difficulties of a serious nature may be apprehended, such as the falling out of stones, or the caving in of whole parts. Any refractory sandstone, or, a still better material, silicious slate, will answer the purpose of such in-walls. Two or more concentric in-walls, one within the other, have no specific use. A second in-wall will be serviceable where the interior lining caves in, and where a continuance of the smelting operations is de-

sirable. Such a lining made of good slate, as that shown in Fig. 98, will answer every purpose.

b. The hearth is a very important part of a blast furnace. A variety of materials are used in its construction. In Sweden and Russia, granite, gneiss, or porphyry; in Austria, sandstone: in most of the furnaces of the Alpine Mountains, marble—at least, in them the bottom stone is of marble: in Germany and France, limestone, marble, sandstone, fire-brick, and cement: and in England and the United States, sandstone. To make experiments on hearthstones, in our country, would be injudicious, for there is an abundance of serviceable material throughout the United States, from the beautiful kaolin, or porcelain clay, of Connecticut, New Jersey, and of other places, to the durable, coarse red sandstone of Arkansas; and as the tendency of our iron furnaces is to produce gray iron, as this ought to be their tendency, and as the ores in use are, almost without exception, oxides, there is hardly any choice left but to take sandstones. The coal fields afford almost every variety of sandstone; from the coarse, conglomerate, mill-stone grit, to the fine-grained, carboniferous sandstone of Portsmouth, Ohio. Every one of these varieties is nearly everywhere accessible. No general tests of the refractory quality of the material in question can be given. The practical is the only test on which we can rely. Fire-bricks have been tried, and, in some cases, with success; but it is doubtful whether fire-brick will answer so well as good sandstone, particularly in stonecoal furnaces.

c. After the lining and hearth are finished, fire may be kindled. This is to be done with great caution, to prevent cracking, or, what is worse, flying of the stones. It is advisable to wash a new lining and hearth, once or twice, with a composition of lime, clay, and common salt; this mixture will dry very hard, and, under a low heat, will readily melt into a very liquid slag, which glazes the whole interior. After fire is kindled, the tuyere holes should be closed, and the top covered by cast-iron plates; this will prevent a strong draught, and

a change of cold and hot air, which would be destructive both to hearth and lining. It is also advisable to cover the sandstones of the hearth with a four-inch lining of common brick, to prevent the direct action of the fire upon the stones. When the hearth and lining have been thus exposed to fire for a week or ten days, they will doubtless become tolerably dry; the hearth may then be filled with coal as high as the widest part of the boshes, and its temperature raised. But we should be cautious to keep the tuyeres shut, and to protect the tymestone either with a stopper of clay or a lining of brick. In filling with coal, we should proceed slowly; and no fresh coal should be applied until the flame rises through the last charge. The furnace may thus be heated within three or four days, if we are careful to keep the coal up and to clean repeatedly below. But if time is not precious, the fore-hearth may be closed up, with the exception of a few small openings, with a brick stopper. This is to be taken out at least every twenty-four hours, and the hearth cleaned of its ashes and clinkers.

d. When a furnace is well dried and heated throughout, and when it is filled to the widest part of the boshes, ore may be directly charged, and then alternately coal and ore, until the furnace is filled to the brim. In this state it must be constantly kept, however fast or slowly the charges may sink. But, if the furnace is not quite dry; if we have any doubt about the matter; or if the stack is new, it is advisable to fill the whole furnace with coal. This is particularly applicable to charcoal furnaces, or small stacks.

e. The charges of ore should be small for the first two or three days, that the working of the furnace may be observed. If everything works well; if the hearth is clean, and the iron gray, the amount of ore may be gradually increased. Limestone, or any other material employed as a flux, generally equals in amount a full charge of ore, the object of which is to clean the lining and hearth from adherent cold cinder and clinkers. When coal is so far consumed that the ore has de-

scended to the tuyere, the hearth may be cleaned once more, the damstone put in its place, and the tuyeres and blast prepared for operation. Charcoal furnaces require very little attention at this time ; but coke and stonecoal furnaces are managed with considerable difficulty. Coke and stonecoal should be kept almost constantly in motion, to prevent the adhesion of clinkers, and the result of that adhesion, scaffolding. This may be done by putting in grates, at least three times every day, by means of ringers and hand bars, as we have heretofore explained. Stonecoal is very apt to prevent the free passage of draft, by depositing small coal, or dust. Bituminous coal, which is very apt to swell, sometimes bakes into large masses or cakes through which no air can pass.

f. The hearth in small furnaces is four inches, and in larger furnaces eight inches, wider than the damstone. An opening for a tap-hole is thus left. This hole is filled up with a mixture of refractory clay and sand, mixed with a little coke dust, to prevent its vitrification. The damstone itself is bedded in fire-clay, and well protected by the dam-plate, of cast iron, two inches thick.

g. The tuyeres at the charcoal furnaces with cold blast are mostly made from a refractory fire-clay. This is a bad habit. The Swedish and German method of employing copper tuyeres is preferable, for it is not only the cheaper, but it saves a great deal of trouble. A copper tuyere is simply a piece of red copper, three-eighths or one-half of an inch thick, bent and hammered into the proper shape. A stonecoal furnace with hot blast requires a water tuyere. This is an article of trade, which we shall describe in another place.

h. The starting of the blast requires careful attention. When the hearth is clean, the damstone in, the tuyeres properly placed, and the blast machine in motion, the nozzles of the pipes are turned into the tuyere, and, for the first few days, about half of the usual pressure applied. At the expiration of one week, the full blast may be put on, and the ore charges gradually in-

creased ; so that a furnace, within three weeks—if a new furnace, within four weeks—is able to produce its full amount of iron. It is advisable to keep the hearth for the first discharges as full of iron as possible. This is the best means of cleaning a hearth below the tuyere.

i. What should be the height of the damstone and cinder-plate, particularly at charcoal furnaces, is a delicate question, the solution of which depends greatly on ore flux, blast, and upon the quality of iron to be produced. The height varies from one inch to three and even four inches below the tuyere. Strong cinder and gray iron require a lower dam than very liquid cinder and white or forge iron. A low dam consumes more fuel, and inclines to gray iron. In stonecoal or coke furnaces, we encounter no difficulty in relation to this point, for the pressure of the blast in these furnaces often renders it necessary to raise the dam several inches above the tuyere.

k. With charcoal a furnace is worked with little difficulty ; but with coal, and still more with coke, the difficulty is augmented. By the use of charcoal, the slag is generally glassy, liquid, and not soon cooled off, if the blast touches it ; but the slag of the coal or anthracite furnace is generally stony, opaque, and easily chilled by the touch of the cold blast. The use of coke is accompanied by still worse results. Where everything is in good order ; where the fluxes are well selected ; where the ore and coal are in proper condition, and the blast steady and dry, scarcely any disturbances happen ; and a drawing of the cinders, with cleaning of the hearth of the charcoal furnace every twelve hours, and that of the coal or coke furnace every six hours, is sufficient. However, should anything go wrong, and should the slag be very much inclined to chill before the blast, thus obstructing the passage of the materials, cleaning is more frequently required, often at intervals of two hours ; but this should be done quickly, for in such cases the furnace is generally in a condition in which it can dispense with the blast only for a short time ; and frequent opening of the forehearth, stopping off the blast, by

cooling the hearth, would make the matter worse. One of the greatest hindrances of good work is the accumulation of small coal or dust in the boshes, or in the corners of the hearth. This accumulation results from a cold hearth, or from a too strong blast. Where such accidents happen, our only resource is to raise the temperature of the hearth, to keep the forehearth shut, or, by means of cinder noses on the tuyere, to throw the blast, as much as possible, in the centre of the hearth. If a hearth is too cold, and, to all appearances, cannot be heated to its proper degree by the utmost care and attention, it is advisable to throw on some dead charges, that is, charges without any ore, the number of which can be increased, according to circumstances, to six or twelve, or even more. In some places, managers are accustomed to reduce the ore charges in cases of difficulty. This is a bad habit, where the obstruction in the hearth is but an accident, and not the result of overburdening. If a furnace has an ore charge, with which it has always worked regularly, it is advisable not to change burden, simply because a disturbance happens; but if the furnace is overburdened by ore, and in consequence of that has become too cold, a reduction of the ore charges, and the application of dead charges, in the meantime, may be required.

The forehearth should be kept closed up, so as to prevent the blowing out of the flame. There is no use whatever in blowing out below the tymp; the heat and blast lost there are quite serviceable in the stack, and of no use whatever at the tymp. They are, besides, very apt to burn the tympstone and tymp-plate, and to cause a premature destruction of the hearth. By keeping the cinder passage open across the tymp—or, if sufficient cinder is not discharged for that purpose, by changing frequently the cinder passage—a warm tymp may be kept without the flame of the blast.

1. The keeping of a furnace has great influence upon the success of the whole operation. If a manager expects workmen to do their duty, he should be careful to furnish them with good tools. Bad or imperfect tools

augment the difficulty of keeping a furnace ; and where disturbances happen, they give rise to much trouble and vexation. Ringers, crow or hand bars, tapping bars, cinder hooks, shovels, sledges, &c., ought not only to be in good condition, but in sufficient number. It may be of service, in instances where a manager has none but inexperienced workmen, to know the duties of the keeper. We shall, therefore, give a brief description of the furnace operations at the hearth.

m. The tuyere, that is, the iron at this place, as seen through a hole back of the tuyere, should be bright and star-like—a condition easily produced by hot blast, but not by cold blast and refractory ores. Clay and argillaceous ores are very apt to chill at the tuyere, and form around it a body of cold cinder, which often increases rapidly, and disturbs the regular work. Such cold masses of cinder are to be pushed into the hearth, and hot coal left between them and the tuyere. With hot blast we experience less difficulty ; still, such ores require more attention than others. In many cases, where gray iron is to be produced by cold blast, from argillaceous ores, it is necessary to produce a prolongation of the tuyere, called a nose, by the workmen, by means of cinder ; this nose is often extended far into the hearth, and then called the dark or black tuyere. In this case, a thin scale of cold cinder, with numerous holes, forms around the tuyere ; this scale should never be permitted to grow so strong that a slight tap with an iron bar is not sufficient to remove it. Every six hours at coal or coke furnaces, and every twelve hours at charcoal furnaces, this nose is to be removed ; and its place supplied by a new one as soon as the blast is in operation. If the cinders are not of a given composition, there is some difficulty in forming such a prolongation of the tuyere ; but some keepers are so skilful as always to succeed, while others frequently fail. This a very advantageous method of working clay ores ; and I have known instances in which the economical advantages of the hot blast were obtained by this kind of tuyere alone. But, if the extension and thickness of such a nose exceed in a cer-

tain degree, as is frequently the case where two or three tuyeres are at work, and where the workmen are inexperienced and negligent, the consequences are so serious and so troublesome as to afford no encouragement to continue such a mode of working.

n. After tapping, or, what is the same thing, after a new start, the hot coals of the interior are drawn forward, as high as the dam; and a stopper, formed of a mixture of sand and clay, is rammed in between the tymptone and the coal, and so well secured that the blast cannot move it, and so tight that the blast cannot play between it and the tymptone. Difficulties often arise in the latter part of the performance. To avoid these, various methods have been employed, in which the most common is, an iron rib, two or three inches thick, cast to the tymptone, and projecting under the tymptone. Another method, previously mentioned, is what is called a water tymptone; but this improvement is of a very doubtful nature. I never saw a well-made stopper fail, if properly attended to: but if the clay is too soft, and not sufficiently refractory; if the stopper is so small that the blast can work through it and the tymptone, of course no stopper will answer. When the hearth is well closed, coal dust or coke dust is thrown over the hot coal, and after this, the blast is turned into the furnace. The coal and dust in the forehearth must be sufficiently porous to permit the passage of the blast, and to show a slight, gentle, blue flame. Within an hour or two hours, according to the dimensions of the hearth and the burden of the ore, the cinder in the interior will rise sufficiently high to stop the playing of the blast through the forehearth; when it may be advisable to open the coal, and to endeavor, by means of a short hand bar, to ascertain whether the cinder has penetrated into the forehearth. If it has not, some stirring and lifting of the coal cinder, at the bottom, will generally be sufficient to fill the forehearth with liquid slag. If a furnace has been for some days in blast, this matter presents but little difficulty; but if the furnace is cold, or newly started, greater attention to it is required. Where the cinder

rises so high as to be seen approaching the tuyere from below, a short bar should be run into the liquid mass, and some warm cinder drawn over the dam, after which a regular current of the cinder will flow off by itself. If, in the course of the work—say within three or six, or more hours—the tuyeres begin to get troublesome, and if cold or tough masses begin to accumulate, and obstruct the passage of the blast, the furnace may be opened, the blast taken off, the stopper removed, and the top of the cinder drawn off, cooled, and removed; then some cold small coal or coke may be thrown over the hot forehearth; after which, the workmen should run a ringer through the whole length of the hearth, from the damstone to the back, moving the point of the bar along the sides, the bottom, and the backstone; and if any lumps of cinder stick anywhere in the hearth, they should be detached, and, by a slanting motion of the iron bar, brought forward before the tymp. Such an overhauling or cleaning of the hearth must be done quickly. If the furnace is not in good condition, two workmen should be employed on it. After the lumps and cold cinder are removed, a little blast is let in, to blow out such dust and small coal as would obstruct the blast, and tend to form more lumps of cinder. When the hearth is thus cleaned, the blast is taken off, and a new stopper rammed firmly in. This is effected with difficulty, on account of the liquid slag below; but, by holding a strong sheet-iron plate between the tympstone and cinder, it may be facilitated. The blast is then turned on, and the work proceeds as before. This kind of cleaning is more frequently needed in coke and stonecoal, than in charcoal furnaces, and generally where, by reason of too wide a hearth, too weak or too strong a blast, or other causes, the furnace is inclined to make dust; for such dust includes the remains of half-smelted ores, which form with it infusible lumps. The toughest clinkers are generally first formed in the forehearth, if the other part of the furnace is in good order; to prevent this, cast-iron plates, all over the tymp and sides,

are very useful, and ought to reach as low as possible into the basin of the hearth.

o. If through accident, or some other cause, the hearth gets too cold; if the reduction of the ores is imperfect, and the cinders black or dark green, great caution is required to obviate difficulties; for generally, in that case, the tuyeres work dark, and clinkers accumulate before them. Our only resource is to open the hearth, and work the furnace, however disadvantageous such a course may be. If we could keep the furnace closed up, and apply the blast, it would recover, in most cases, by itself. But commonly there appears to be nothing in the furnace but ores; these come down rapidly, and sometimes pile up fast, when no other resort than to open the hearth, and to take the cold stuff out, is left us. At this point of the operations, if at any point, fast work is required, for the hearth cannot bear any reduction in temperature. Where the damstone can be conveniently lowered, or where the cinders can be kept by any method low at the tuyere, so that the blast cannot touch the surface directly, much trouble and difficulty will be avoided.

p. The tapping of the iron may be effected with comparative ease at charcoal furnaces; but at stonecoal furnaces, it is done with less facility. In the first case, there is scarcely any possibility of failing to make gray iron from the start. This iron is but little inclined to chill at the bottom; and the hearth may be kept free of it very easily. But at stonecoal furnaces, during the first week or two weeks, scarcely any gray iron can be expected: and the white iron, however liquid it may be, is very apt to chill, and disturb the tapping-hole, which, if once filled with cold iron, is not easily opened. The general plan is, to blow through the tapping-hole after the iron is let out; and where cold iron sticks in the bottom, this is almost the only means by which the cleaning of a hearth in stonecoal furnaces may be effected. To this subject too much attention cannot be paid, because, of all the disorders which arise, chilled iron in a hearth is the worst.

q. It is not difficult to assign a reason for most of the disorders which occur in a blast furnace. We shall, therefore, call the attention of the iron manufacturer to the causes of some of them. Upon the location of a furnace a great deal depends. The furnace should be in a position where storms and gales are not likely to affect it. Where it is placed against a hill-side, care should be taken that no moisture from the hill shall come in contact with the stack. Even a tunnel head bridge of timber presents a questionable advantage, where it should, through any circumstance, be the means of conducting rain water to the stack. Moisture in the upper part of the stack tends to cause scaffolding in and above the boshes.

r. A wet or cold bottom stone tends to chill the iron and cinder below the tuyere; this occasions a reduction of yield, and an inferior quality of metal, besides causing trouble in keeping. Wet, or imperfectly prepared stock occasions irregularities of a very perplexing nature, which sometimes appear to be unaccountable.

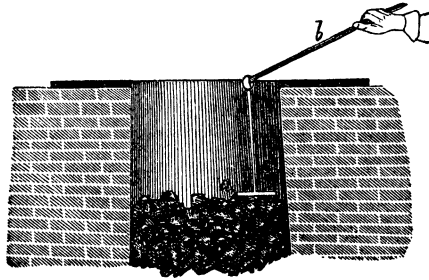
Too weak blast reduces yield, and is injurious to the hearthstones.

Too heavy blast, which happens less frequently, reduces yield, by its tendency to deposit coal dust in the corners of the hearth, and on the top of the boshes, from the mechanical destruction of coal. It facilitates the formation of lumps and balls of half-melted cinder, which are very troublesome to the keeper. The disadvantages of a new, or not perfectly dry stack, are but temporary; a heavy stack, that is, a large mass of masonry, requires of course more time and fuel to dry it than a small stack.

s. A furnace should be filled very regularly; that is to say, every new charge of coal and ore should just fill the furnace, and no more than fill it. To secure this regularity, a charge measure is generally employed at charcoal furnaces with narrow tops. This measure is constructed of two half inch round iron bars, so connected at one end that one bar sinks into the furnace while the other serves as a handle. Fig. 95 represents this arrangement: *b* is the handle, and *c* the measure; a little cast-

iron plate, *a*, prevents the sinking of the rod into the spaces between the materials, and prevents errors. At

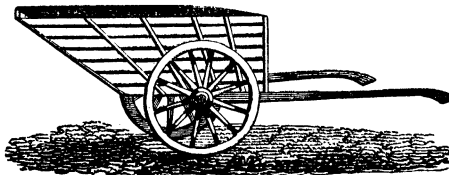
Fig. 95.



Charge measure.

coal or coke furnaces, or furnaces with wide tops, this measure is unnecessary, for the material is not permitted to sink very low before another charge is filled. Irregular filling produces irregular work, and bad iron, as well as trouble to the keeper. The common way, at charcoal furnaces, of filling coal by the basket, is a very imperfect method of measuring, for some baskets contain but two bushels, while others contain three bushels and even more. The English coke barrow is preferable to baskets, and, at many furnaces, is employed. It is a two-wheel hand-cart, of the capacity of twelve or fifteen bushels. It is represented by Fig. 96. But where the

Fig. 96.

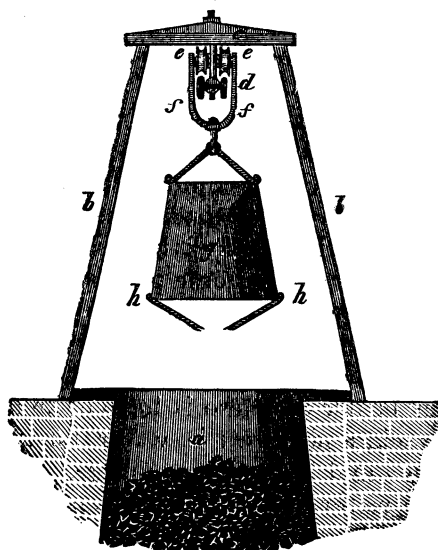


Coal barrow.

stock is to be hoisted, and no tunnel head bridge leads to the top of the furnace, such barrows cannot be employed. Sheet iron boxes, of capacity sufficient to contain one charge, are more useful still, both for coal and

ore; these boxes, being lifted or put on light wagons, are pulled by a horse to the hoisting place, or to the tunnel head. Frequently we find rails laid, on which these sheet-iron wagons run; these reach across the furnace top. But this is accompanied with some difficulty, for if the road to the top is too small, the flame will play round the rails; and a stream of water, which it is sometimes inconvenient to obtain, will be required to cool them. Nevertheless, such boxes and railroads are very useful, and it is to be wished that they were more extensively employed. To assist in spreading abroad the knowledge of an arrangement for filling, which is very much needed, I propose the following improvement, on the principle of a railroad. In Fig. 97, *a* represents the

Fig. 97.



Suspension railroad for filling.

furnace top, *b, b* two posts of iron or wood which carry the cap *c*; on *c* a double or H rail of cast iron, *d*, is fastened, on whose two flanges the wheels or pulleys *e e* run. The horseshoe *f, f* connects both wheels, and serves to suspend and fasten the sheet iron box *g*, which

contains the ore or coal to be charged; the bottom of the box is movable in halves, at the hinges *h, h*, and will, if opened, drop the contents of the box at any place where it is desired, and of course, therefore, just in the centre of the furnace, if wished. The bottom of the box may be altered agreeably to any particular notions; and the form of the box may also be altered; but we are inclined to believe that a simple square or round vessel, with a movable bottom, will answer every purpose. Such a railroad, sufficiently high to permit everywhere a free passage under it, may be extended over the yard, and may be made even movable, so that it may be brought to the spot where ore and coal are to be loaded. At the fastening point, where the box is suspended from *f, f*, a kind of steelyard scale may be applied, so that loading and weighing may be effected at the same time.

Where furnaces are located in plains, it is necessary to hoist their stock either on inclined planes, or in perpendicular towers. A variety of plans to effect this object have been designed and executed; but, of all these, that most in use is one which was first introduced at the Crane Works, Catasauqua, Pa., and is now to be found in many other establishments. A reservoir of water is put upon the tunnel head bridge, where it is kept filled by means of force-pumps from the blast engine or waterwheel. An iron chain suspended over a pulley carries one or two buckets of sheet iron, sufficiently heavy, when filled, to balance a charge of ore or coal. When either of these is loaded below, the filler turns a stopcock, and fills the water bucket or barrel, which descends and lifts up the charge. A valve in the bottom of the water cask, which is opened by a simple arrangement, permits the water, when it arrives at the proper place, to escape. The platform containing the ore or coal, relieved from its burden, is charged with empty boxes or barrows, after which it descends, and the water barrel again rises. In this way the duty is performed where but one water cask is employed, which is quite sufficient for one furnace; but where two or more furnaces are to be supplied by the same mechanism,

two water casks, one on each end of the chain, are applied, to avoid the loss of time caused by the descent of the empty boxes. Sometimes an endless chain is applied, by way of compensation for the inequality of length in the working chain.

The filling of furnaces has been, until the present time, a source of much anxiety and doubt, and there is no question that many imperfections and disturbances in the furnace operations are attributable to the carelessness with which this has been attended to. As good results will always depend more or less on the conscientiousness of the workmen, even where the best arrangements exist, the plan which promises most success is to employ honest men for the performance of that work.

t. Coal charges are most commonly measured, particularly at charcoal and coke furnaces; but at some of the stone coal furnaces, coal as well as ore charges are weighed, a custom worthy of general adoption. Whether irregularities by weighing, or those by measuring, are the greater, is a doubtful question. My own experience leads me to decide against the latter. In any well-regulated yard, the charcoal charges by weight will be found to work more regularly than those by measurement. With respect to coke and stonecoal, the rule holds equally good, because, in the latter case, a small difference in the measure will have considerable influence upon the amount of carbon put into the furnace, and will consequently affect the operations. Generally, this difficulty is attempted to be met by means of larger charges; but these are altogether ineffectual for the purpose. Charcoal from hickory and maple wood is nearly twice as heavy as that from poplar. If, with respect to coke, the difference is not so great, it is at least sufficient to account for many difficulties in the furnace operations. The weighing of stonecoal is necessary, on account of its great specific gravity.

The moisture which charcoal absorbs from the atmosphere constitutes one of the main objections to weighing it; but this objection is not a solid one, for the coal absorbs almost as much moisture within the first twen-

ty-four hours after it is charred and cold, as it absorbs during the following six months. With respect to coke and stonecoal, this objection does not apply at all.

Coal charges are usually of a given measure or weight, and should any alteration in their relative quantity be required, this is effected in the charges of the ore. The amount of fuel for one charge is in charcoal or coke, from ten to fifteen bushels, equal to from 450 to 600 pounds, and in anthracite furnaces, from 600 to 1200 pounds. The amount should be determined by the size of the top; narrow throats receive larger, and wide tops smaller charges. In estimating the quantity of coal required, the quality of the ore must be taken into consideration. Very refractory ores work better with large than with small coal charges. The former have a tendency to raise the heat in the hearth, because of the interval between the different ore charges that descend into it.

u. The size of the charcoal, coke or stonecoal considerably influences the working of a furnace. Coarse coal is apt to leave large spaces, through which small coal and small ore will work down to the hearth in a condition unfit for service. This disadvantage is greater in low than in high stacks; but in both cases, it should be avoided. In relation to coke and stonecoal furnaces, our remark concerning the influence of the size of coal has especial application; for, as coke is more incombustible than charcoal, small coke will be more apt to remain unconsumed in the furnace, to mix with unreduced ores, and to form with them lumps, which, descending into the hearth, and arriving before the tuyere, are apt to form cold clinkers, of difficult removal. To avoid fine dust in anthracite furnaces is a matter of great difficulty, because anthracite is very apt to fly, or to throw off small bits of coal, when suddenly exposed to a high temperature. The surest means of preventing this are large throats and cool tops, which will, if not effectually remove, at least, modify the evil.

v. Immediately after a coal charge is filled, a charge of ore is thrown into the furnace. The common and

undoubtedly the best manner of doing this is to weigh the ore, and if anything in the furnace should go wrong, to diminish or increase the ore charge. Where small boxes are used for filling ore, which is generally the case at charcoal furnaces, they ought to be as much as possible of equal weight. On this account, sheet-iron are preferable to wooden boxes, because they do not absorb moisture, which, in case of rainy weather, would diminish the charge of ore. The best of all is an iron box, sufficiently large to contain a charge. The filling of ore by the measure should be repudiated altogether. If this method is tolerated in the case of coal, it will not answer with ore, for ore is of great specific gravity, and an imperceptibly small quantity may amount to more than the necessary regularity of the furnace operations will admit. It must certainly be admitted that, in most instances, even a small variation in the charge of ore cannot be borne by a furnace, particularly where its operations are carried to a high state of perfection, and where the burden is kept at the highest pitch. Filling ore by the measure is still more imperfect where small boxes are used than where the whole charge is contained in one vessel.

w. The objections made against too small or too large coal will apply equally well against ore that is too small, or sandy, or too coarse. Low stacks and small furnaces suffer more from such causes than high stacks, or furnaces of large capacity. Fine, sandy ore runs through the coal into the hearth, without being properly prepared, and occasions the production of white iron and black cinder; too coarse ore arrives in the hearth in a state unfit for reduction, and of course unfit to produce good work.

Wet ores, and ores that are either roasted too hard, or not roasted at all, produce bad results; and the smaller the furnace, the worse the results. In this case, even light ore charges are not wholly successful; while the application of strong blast, or the fast driving of the charges, only increases, instead of obviating, the difficulty. Weak blast and light ore charges can alone

favorably modify these accidents. Close attention to the preparation of the ores is thus seen to be indispensable. Hence, it is apparent that too much care cannot be taken in the proper treatment of the ore where nature has not already done most of the work, that is, by oxidizing and breaking the ore; luckily, in three instances out of four, this is the case in our country. The difficulties arising from such disorders are more serious in charcoal furnaces and low stacks than in coke or anthracite furnaces and high stacks. Too hard roasted ores, partly melted into clinkers, are not much better than cinders from the forge fires or puddling furnaces, and produce the same results. From these ores it is almost impossible to smelt gray pig iron.

x. A successful business is scarcely possible without a judicious selection and admixture of the smelting materials. Rich ores are apt to contain less foreign matter than is needed for the formation of a sufficient quantity of cinder to protect the hot iron against the influence of the blast; the production of white iron, and the consumption of more fuel than is actually necessary to reduce the ore, are the results of this deficiency. In this case, an admixture of poor ores will be found advantageous. Poor ores of a refractory nature consume much coal, and furnish a small quantity of iron; but a great deal can be accomplished by the application of hot blast. With respect to rich ores and cinder in small quantity, the hot blast is of but little advantage. We shall arrive at a thorough understanding of this question in the course of this and the following chapter. We shall allude here to those applications which were considered useful, and generally adopted, before the science of mixing ores was established.

The primary aim of the iron manufacturer is to arrive at perfection in the smelting operations, that he may be enabled to produce from a given amount of coal and ore the largest possible quantity of metal of a definite quality. This object can be realized by a judicious selection and mixing of ores; and where, through want of material, this is not practicable, by a proper selection

and addition of fluxes. Nearly every material mixed with the ores is in itself more or less refractory; but, where several are mixed under proper circumstances, they will melt together, and be, to a greater or less extent, liquid. The protoxide and peroxide of iron may be considered infusible by themselves; but melt when mixed. Quicklime, clay, sand or silex, and magnesia, are also very refractory by themselves. Protoxide of iron melts readily when mixed with silex or clay; and forms, with these substances, a very liquid cinder, in forge fires and puddling furnaces. Lime and magnesia melt together with silex, but require a very high temperature. If, however, a little clay is added to the mixture, the melting is facilitated; and if a small portion of the oxides of iron is added, the mixture will flux at a still lower temperature. These observations can be made at a coke or anthracite furnace. Potash and silex melt readily together; so also do soda and silex, or, what is the same thing, sand and soda; but a mixture of potash, soda and sand melts with greater facility. If we add potash or soda, or both, to the above mixture of lime, magnesia and silex, the melting point of the whole will be lowered; this is somewhat remarkable, because the sand or silex can be increased in a greater ratio than the potash and soda. From this it follows that the greater the number of such elements in furnace cinder, the more easily the cinder will flow; or, in other words, that the more we mix and multiply the kinds of ore, the more regularly the cinder will flow. Silicious ores, calcareous ores, and clay ores are, singly, very refractory and troublesome in the furnace. Ore mixed principally with silex, requires a high temperature to produce iron, on account of the refractory nature of the admixture. But it will readily make gray iron. Calcareous ore, or iron ore mixed with lime, is equally refractory by itself, requires a high heat for smelting, and is inclined to make white iron. Clay ores are not very refractory; if no lime or potash is present, if the ores are not very rich, they do not make iron at all, or make it in very small quantity; for a great deal of the iron is

consumed in fluxing the clay. If we mix calcareous and silicious ores together, they will not only produce iron with greater facility than each would separately produce it, but they work with less coal; and if to this mixture we add an ore belonging to the aluminous or clay ores, the operations in the furnace will, in every respect, prove still more satisfactory. There are many more admixtures, as may be presumed, which influence the manufacture of iron; but the above constitute the main body of foreign matter mixed with iron ores.

If, through the influence of local causes, we are unable to obtain such a mixture of ore as will satisfy us, we are compelled to add such foreign matter as will produce satisfactory results. Purely silicious ores will require an addition of clay ore and pure limestone, or, if no clay ore can be obtained, argillaceous limestone; and if the latter cannot be had, any mixture of clay and iron, even blue clay, will answer. Fire-clay, or any pure clay without iron, we cannot recommend; but, if it is necessary to make use of such material, it will be advisable to dissolve it, and to mix it well with fine ore. Limestone or calcareous ores require the addition of silicious and clay ore; and if these cannot be obtained, ferruginous shale, which generally contains both silex and clay, will answer. But this shale is to be roasted like ore, because it frequently contains sulphurets of iron (iron pyrites). Clay ores generally contain so much silex, that no addition of sand or silicious ore is needed. For these, lime is a sufficient flux. It is a common practice to flux the ores, for which purpose limestone is, in this country, in most instances employed, because the main body of the ores are of a silicious and clayey nature. But if, in the case of silicious ore, an argillaceous or magnesian limestone, and, in the case of clay ore, a silicious limestone, be selected, the result will be highly favorable. In all cases where limestone or any other flux contains a little iron, the smelting operations will be facilitated; and a mixture of ore will produce the most perfect work. The addition of dead fluxes is thus rendered unnecessary. We cannot too

much insist upon the importance of this subject, for upon it depend, to a greater or less extent, the quality and quantity of the metal, and in consequence the success of the business. There is a point where the liquidity of the slag ceases to be of advantage. Ores which contain feldspar, as is generally the case with the magnetic ores, flux, in most instances, too readily; in which case, a more refractory material, such as silex or clay, is to be added. The silicious ores of Eastern Pennsylvania require a large amount of lime; but where clay ores can be added to the lime, as in Huntingdon County, they work exceedingly well. The Eastern States do not, in this respect, enjoy equal advantages with the Western States. In fact, from the eastern boundary of Pennsylvania to the western boundary of Arkansas and Missouri, the coal measures—to a greater or less extent everywhere accessible—contain this material in abundance.

Where small boxes are in use for filling and weighing ore, the distinct separation of the ores and flux is a matter of no difficulty; but where only one box is used for the whole mixture, much attention is required. The flux, as well as the ore, should be filled by weight; not, as frequently done, thrown in at random by the shovel. For, let it be well remembered that the quantitative mixture of ore, or ore and flux, is definite; it is not a matter of indifference, in seeking to obtain the best result, how much we take of one kind of ore and how much of another, or how much limestone or flux we use. Too great is as injurious as too small a quantity of limestone. If the quantities of ore and flux are determined, it is a good practice to mix all the ores previous to being weighed. This mode of mixing the ores has from time immemorial been practised in Germany. It increases to a small degree the labor of the yard, but richly repays this labor in the better work of the furnace. The process, called by the Germans *Moellerung*, is, simply to spread on some level place a certain quantity, say one hundred wheelbarrowsful, of one kind of ore; upon this, half that quantity of another kind; upon

the latter, one-fifth or one-sixth that quantity of a third kind; and over the whole, the limestone or flux, if any is needed. Beds from one to two feet in height are prepared in this way, from which an amount sufficient for a charge is taken. The mixing of the ores can, in this manner, be watched, without the necessity of intrusting its management to unthinking workmen.

The ore should be spread uniformly over the coal in the furnace; but where the blast is weak, or the ores wet and earthy, it may be advisable to pile the ore in the middle of the throat, that the rising gases may escape. This should be avoided, if possible, on account of the coal consumed. Furnaces which have but one charging place are often badly managed, because the fillers either charge indiscriminately, on either side, or, what is still worse, one filler is in the habit of throwing the stock to one side, and the filler of the next turn to the other side. These irregularities give rise to changeable work in the hearth, to the formation of lumps in the hearth and boshes, and finally, what is generally the case when the furnace is well heated, to scaffolding in and above the boshes; which, of course, is likely to be attended with serious consequences.

Ores which contain zinc, arsenic, or chlorides, are apt to scaffold, at some point of the upper part of the in-wall, in charcoal furnaces. In this respect, stonecoal or coke furnaces are in no danger. For this evil, small coal charges and a hot top are the best remedies. Sufficiently wide throats, and the heating of the ore in the middle of the coal, are required, to keep the lining as warm as possible, and to permit the evaporated metals to escape.

y. The number of charges brought down in twelve or twenty-four hours, or the quantity of iron produced, depends very much on the amount of blast sent into the furnace. Nevertheless, we may remark that the quantity of air does not determine with certainty the descent of charges, or the quantity of iron made. A cold hearth never produces so much iron as a properly heated furnace, where the blast, in both instances, is the same.

If the hearth is too warm, nearly the same difficulty occurs. A liquid, lively cinder makes a far greater quantity of iron with a given amount of blast, than a tough, chilly cinder. Cold, black, or dark green cinder produces still less iron, and is, on the whole, the least advantageous. A clean hearth, free of clinkers and cold iron, is, of all others, most likely to produce good metal, and in abundant quantity.

z. The question, what number of tuyeres it is most profitable to use in a furnace, is difficult to answer. It can be decided only by experience. Nevertheless, we shall present some conclusions drawn from experience. Where cold blast is used, we should be in favor of never applying more than two tuyeres, and of trying very hard to do with one; but where hot blast is used, two or even more tuyeres are almost indispensable, for the following reasons: In the smelting process by cold blast, as strong a pressure in blast as the fuel will possibly bear is highly advantageous. This fact favors the use of as few tuyeres as possible, for, if heavy pressure is applied, the more tuyeres we have, the more coal we destroy. In addition to this, the dust in the hearth and boshes increases. With hot blast the matter is different. There is no need of pressure; and by the tendency of the hot air to combine more readily with the coal, small coal, which does not burn well, is very apt to gather in the corners of the hearth, and produce difficulties that are well known. Therefore, the same reasons which are in favor of as few tuyeres as possible with cold blast, are in favor of as many as possible with hot blast.

It is sometimes the case that the gray iron from the furnace is directly used for foundry purposes, such as to cast hollow ware, stove plates, &c. This mode of making use of the hot metal is practised only at a few charcoal furnaces. In many respects, this is a bad practice, and should be avoided. The disturbance which it occasions to the smelting operations more than counterbalances the advantage gained; and, besides, the castings of remelted iron are preferable to those cast directly from the furnace.

aa. The time at which the iron should be let out is

generally so arranged that the workmen, changing every twelve hours, have each their even number of casts. The preparation of the pig bed, moulding of pigs, is the duty of the keeper, or, at large furnaces, of the helper, or second keeper. The founder generally assumes the duty of tapping the iron.

bb. If the melted iron remains too long in the furnace, it is very apt to turn white, on account of the action of the blast. Such an accident should be avoided, for it is injurious both to the furnace and to the iron. But in charcoal furnaces, the inconvenience is not so great as in anthracite and coke furnaces. If, in an anthracite furnace, the cinder rises too high, it is very apt to adhere in lumps to the hearthstones; after the iron is let out, we are forced to break away these lumps with great caution. In charcoal furnaces, however, the action of the blast is frequently resorted to for the production of white iron for the forges; and should the original iron have been gray, or mottled, a strong forge iron is produced. At many European furnaces, where forge metal is manufactured, the desired effect—that is, the production of white, strong metal, with the least expenditure of coal—is obtained by some peculiar method of twisting and dipping a tuyere. This manœuvre, at the Wülf's oven and the blue oven, is applied to the ores of the primitive and transition formation, as spathic and magnetic iron ores. It would be of no use, in this country, at places where oxides for the production of gray iron are principally smelted. Where white iron is smelted by a high tuyere, or, what is the same thing, where the iron cannot be reached by the free oxygen of the blast; and where it is smelted by a weak blast, or a too wide hearth, it is always bad, weak, does not yield well, and does not make good wrought iron.

cc. If no accidents or disturbances happen in the regular furnace operations, and if everything is in proper order, the quality of the metal, that is, its amount of carbon, is entirely dependent upon the burden. Small burden will produce gray, and heavier burden white iron. In the former case the furnace will be inclined to dry

the cinder, that is, to deposit balls in the hearth, by which the hearth is cooled, and the temperature frequently brought so low as to produce a tendency towards the other extreme, that is, black or dark green cinder with white iron. Such changes are very disadvantageous, and should, by all means, be avoided. A well-conducted furnace should never be too heavily, and never too lightly charged, for one extreme is as bad as the other. A medium course is the most profitable, that is, to make mottled iron, and trust to accident for the manufacture of gray or white iron; for both, in certain cases, will be produced. In this way the furnace will carry the heavier burden, and the result will be, in either case, a good forge metal.

White iron is produced by a cold furnace; but it can be made by a hot furnace. The white iron of too heavy burden always proves a good forge iron; but the white iron of too light burden is of a very doubtful nature, and in most instances is bad, if smelted from the ores of the coal formation. It is very bad, if made by hot blast, anthracite, or coke. The making of white iron can sometimes be prevented only by carrying as heavy a burden as possible.

dd. The mixture of ore and flux is, with respect to the quality of the metal, a matter of great importance, for too much lime will, under all conditions, produce white iron. If the hot slag, as it flows from the furnace, blazes, and gets spongy like pumice stone when sprinkled with water, we may conclude that lime exists in too great quantity in the charge; but if the cinder appears of a dark, black, or green color, even after the temperature in the hearth is raised; and if the slag in the furnace, in spite of the heat, is inclined to form balls, to blacken the tuyere, and to stick to the hearthstones, we may conclude there is not sufficient lime in the charge. Clay ores are very apt to clinker before the tuyere, even where an abundance of limestone is present; but the limestone may be diminished by the application of hot blast. If the composition of the ores is such as by itself to make a very liquid cinder—which, with bog ore,

shell ores, or calcareous ores, is frequently the case—we must not expect gray iron, until with this composition we mix silicious ore. Silicious ore is highly favorable to the manufacture of gray iron; in fact, foundry iron can hardly be made without it. To produce such iron, a strong cinder and a hot furnace are required. The least disturbance which tends to cool the furnace will cool the tough cinder, and in this way often produce very troublesome scaffoldings in the hearth or boshes.

ee. The color of the cinders is not a safe criterion by which we may estimate the working of the furnace. Gray cinders may contain as much iron as green or black cinders. But, as a general rule, the former indicate better work than the latter. Where the charcoal furnace is in good condition, they are generally well glazed, transparent, and of a greenish color. Perfectly gray, spongy, white, and black or olive-green cinders are not the most favorable indications at a charcoal furnace. Anthracite and coke furnaces, when well conducted, generally furnish a gray, stony-looking cinder, but always well glazed. In these furnaces, spongy, or green, or black cinders are almost as unfavorable indications as in charcoal furnaces. Those which lose their glazing, or fall to pieces, by being exposed to the influence of the atmosphere, contain too much lime, and never fail to make white iron of inferior quality. That their color is no indication of the quality of the metal, is evident; for the ore or coal may contain the oxides of other metals, which generally produce various shades. Variegated cinders, like agate, indicate that the ore or flux employed is too coarse, or, what is still worse, that there is scaffolding in the furnace. Small stacks, or narrow hearths, are endangered when they work coarse ore. In a large anthracite furnace with a wide hearth, so much pains need not be taken in breaking the stock, for there is scarcely a possibility of choking or scaffolding such a furnace.

ff. If any accidents occur, such as scaffolding below or above the tuyere, or in lining, it is a bad practice to throw in, at the tuyere, materials either to flux or heat

the furnace. Lumps and coal cinders below the tuyere can be far more easily removed by means of the bars and ringers than by means of fluxes thrown into the tuyere, or thrown below the tympan; for the addition of fluxes does nothing more, at best, than to remove the lumps where they are the least troublesome. Scaffolding above the tuyere, when it impedes the blast, or the descent of charges, is to be removed by the withdrawal of the ore charges; and, if considered dangerous, by sinking the materials in the furnace to a point very near or above the boshes, and melting away, by means of scrap iron with limestone, as in a cupola, any obstruction in the hearth or boshes. All difficulties may thus be removed in a very short time. Obstructions which endanger the progress of the smelting operations, by so choking or chilling the hearth that coal cannot descend, are the results of inexcusable neglect—inexcusable both to the manager and to the workmen. Charcoal furnaces are but little exposed to such disorders; but coke and anthracite furnaces are very much exposed to them, if they smelt gray iron; for, in the manufacture of this iron, a narrow hearth and strong cinder are required. When, in such furnaces, the least disturbance takes place, the cinder is very apt to stick to the boshes or hearth, and a green, and at last a black, cinder and white iron are produced. So long as the cinder is only of a light green color, or streaked with green, no danger need be apprehended, and the furnace may be considered in good condition; but so soon as brownish streaks in the cinder appear, the furnace should be watched. If the brown color does not disappear within five or six hours, it is advisable to diminish the ore charges, for this color deepens so rapidly, that within twenty-four hours the cinder will become black. If light charges should not be near at hand, the difficulties would thus be greatly augmented.

gg. The flame of the tunnel head, as well as that of the tympan, is indicative of the nature of the operations in the furnace. At charcoal and coke furnaces, a heavy dark top flame indicates that the furnace is cold, and

that the burden is too heavy. A bright smoky flame, which throws off the white fumes, indicates a too liquid cinder; that too much limestone is present; or that the burden is too light. If the iron is gray, the burden can be increased; but if it is white, this should be done cautiously. The withdrawal of a portion of the limestone will generally cure the evil, if the iron is white; but if it is gray, heavier burden is required. An almost invisible, lively flame at the top is significant of a healthy state of the furnace. The strength of the top flame of an anthracite furnace is proportionate to the amount of hydrogen the coal contains; and therefore this is, at best, but an uncertain indication of the state of the furnace. If the flame appears to be struggling to break through the tump, we may be sure that there is something wrong in the interior. But this depends upon the ore and coal, upon the form of the stack, and upon the blast. It is common where small ore is used, and where the hearth and top are narrow. The color of the tump flame is, like that of the top flame, indicative of the work in the furnace; and the rules applicable to the one are applicable to the other. The color of the flame will be more or less modified, according to the foreign matter the ore contains. If it contains zinc, arsenic, and lead, the flame will always emit white fumes, whether the furnace be cold or warm. If the materials contain common salt, the flame will emit fumes of the same color. Where the flame wavers, that is, where it is sometimes large and sometimes small, there is, without doubt, scaffolding in the lining. In this case, close watching of the sinking of the charges is needed. If it is found that all is not right, a reduction of the burden and an increase of blast must be resorted to.

hh. The gray metal, where the operation has been good, is very liquid, and keeps liquid for a long time in the pig bed. If of good quality, it is, even in the thinnest leaf, perfectly gray; but if inclined to white, the corners of the pigs, and thin castings, will be white. This iron appears perfectly white when liquid; while

white metal is of a somewhat reddish yellowish color, and throws out sparks. White metal chills very soon in the moulds, and assumes a rough, concave surface; it adheres, with much tenacity, to the iron tools used for cleaning the hearth. If metal contains sulphur, it is very apt to throw off fumes of sulphurous acid, or sulphuretted hydrogen. It throws off sulphurous acid, if smelted by coke or coal, and neutral or proper cinder, and sulphuretted hydrogen, if lime is used in large quantity, which is generally the case, because such iron cannot be smelted without an excess of limestone. Phosphorus can be detected only by an analysis of the metal.

ii. After the metal in the moulds is cooled, it is to be removed, weighed, and stored; and the sand of the pig bed dug up, wetted, and prepared for another cast. The cinders at small furnaces are easily removed in common carts. At stonecoal furnaces, various methods have been devised to remove the large mass of cinder daily produced, of which one at present practised at some of the anthracite furnaces may be considered the simplest. It is this: Dig two round basins of about five or six feet in diameter, and two feet in depth, at the side of the stack. In the centre of each basin, put a piece of pig metal, in an upright position. Around this pig metal, the cinders, which run into the basin, gather. A chain attached to a crane is then fastened to the pig metal, by means of which the cold cinder is placed upon any suitable vehicle, to be carried off.

A whole volume might be written without exhausting what could be said on the management of furnaces, and of blast furnaces in particular. But our space is limited, and we wish to avoid prolixity. Many occasions will arise, in the course of this work, which, we hope, will enable us to supply whatever deficiency our statement may, thus far, have exhibited.

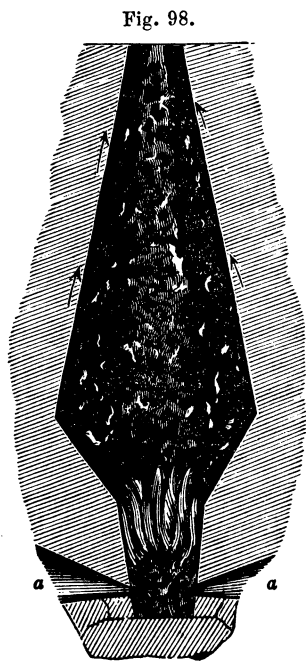
CHAPTER V.

THEORY OF THE BLAST FURNACE.

THE fuel used in the blast furnace is composed, to a greater or less degree, of carbon, hydrogen, and sulphur. If oxygen or atmospheric air combines with carbon, the result is either carbonic oxide or carbonic acid; at a high temperature, with a sufficient supply of air, always carbonic acid. A suffocated combustion, with an excess

of fuel, generally produces carbonic oxide. The result of the combustion of hydrogen and oxygen is always water; that of the combustion of sulphur and oxygen always sulphurous acid.

Combustion in a blast furnace is, as may well be expected, of a somewhat complicated nature, and requires illustration to be understood. Fig. 98 represents a section of a blast furnace in operation, filled with coal, ore, and fluxes. If we introduce at *a, a*, the tuyere holes, a current of air or blast, combustion in the lower part will ensue; and, according to circumstances, the product will be carbonic acid to greater or less extent. But if we have an excess of fuel, and a limited supply of



Theory of the blast furnace illustrated.

air, the final product of the combustion will be carbonic oxide. The immediate combination of carbon

and oxygen at the tuyere forms carbonic acid ; and this carbonic acid, in its progress through the coal, combines with more carbon, and forms carbonic oxide. Carbonic acid cannot combine with any more oxygen than it already possesses ; but carbonic oxide will combine with as much more as it already contains. Carbonic acid is of no use in reviving iron from the ore, for the ore is a combination of iron and oxygen ; and carbonic acid could not abstract any oxygen from the ore. But carbonic oxide will combine with whatever oxygen is present in the interior of the blast furnace.

Practical investigation has demonstrated that the more friable and tender the coal is, the more easily oxygen combines with it ; and that the more compact it is, that is, the greater its specific gravity, the greater is the difficulty with which it combines with oxygen. Heated air combines more readily with fuel than cold air, and of course is more inclined to form carbonic oxide. Soft, open fuel and heated air form carbonic oxide, the agent in the reduction of the ore, more readily than hard coal ; and we may conclude that charcoal and coke are more useful than anthracite coal in the manufacture of iron. According to this statement, the atmosphere of oxygen and carbonic acid will be a zone of greater or less radius, of which the mouth of the tuyere is the centre, as the circular lines in the engraving indicate. The radius of this zone has been found, by experiments made on furnaces, to vary, according to fuel and blast, from six inches to four or more feet. Applying what we have said to a common furnace, with grate and draft, the column of carbonic acid will be from six inches to four feet in height, if we pass a current of atmospheric air through hot and burning fuel. If the column of fuel is higher than this, the carbonic acid will be gradually converted into carbonic oxide. This process is exactly the same in the blast furnace ; the oxygen of the atmosphere is gradually converted into carbonic acid, carbon with much oxygen—and then gradually into carbonic oxide, carbon with less oxygen. Where the atmosphere of carbonic acid ceases in the blast furnace,

we may conclude that the working of the carbonic oxide upon the ores commences, and that it changes more or less in its course upwards. The ascending current of the gases, in a blast furnace, consists, then, of carbonic oxide, hydrogen, and combinations of hydrogen and carbon. These latter gases are derived directly from the fuel, above the reach of free oxygen, and constitute gaseous combustibles, ready to unite with oxygen. Mixed with the above are steam, carbonic acid and nitrogen—incombustible gases which have not the least influence upon the ore. The nitrogen is derived from the atmosphere.

The ascending current of the gases from the tuyeres differs in composition according to height: of course this composition will not be alike at a given height in two furnaces of different construction, and in which different materials are used. Actual experiments on furnaces carried on by hot blast and charcoal have furnished the following results:—

Directly above the tuyere.	Nitrogen.	Carbonic acid.	Carbonic oxide.	Hydrogen.
8 feet	63.07		35.01	1.92
13 "	59.14	8.86	28.18	3.82
22½ "	57.80	13.96	22.24	6.00
25½ "	57.79	12.88	23.51	5.82

We find here, what might have been expected, a gradual increase of the carbonic acid. This is generated by the contact of carbonic oxide with the ore. The relative amount of the different gases is not equal in different furnaces, for, in another case, the gases were mixed in the following proportions:—

Directly above the tuyere.	Nitrogen.	Carbonic acid.	Carbonic oxide.	Hydrogen.	Carburetted hydrogen.
5¾ feet	64.58	5.97	26.51	1.06	1.88
11¾ "	63.89	3.60	29.21	2.07	1.07
17¾ "	62.34	8.77	24.20	1.33	3.36

The gases of a coke furnace exhibited the following composition:—

Directly above the tuyere.	Nitrogen.	Carbonic acid.	Carbonic oxide.	Hydrogen.
2 feet	61.07	0.68	36.84	1.41
17½ "	64.66	0.57	33.39	1.38
28 "	63.59	2.77	31.83	1.81
31 "	60.70	11.58	25.24	2.48

There are, particularly in coke furnaces, gases of a compound character; but these have little to do with practical results, the aim of our investigations.

From the above, it is apparent that the carbonic acid gas increases as the current of gas ascends; and that, on an average, one-third of the carbonic oxide has been converted into carbonic acid before escaping at the top. If the carbonic oxide is the only reagent in the conversion of ore into iron, we may conclude that one-third of the fuel has been properly applied for the purpose for which it was designed. We here have evidence that all the fuel has not done its duty; otherwise, all the carbonic oxide would have been converted into carbonic acid, and all the hydrogen into water. But such is not the case. If a furnace works well, there will be more carbonic acid at the top of the charges than there will be if a furnace works badly; this circumstance accounts for the different appearance of the tunnel head flame.

The theory of the reduction of ore will then be simply this: the gases ascending in the furnace leave a part of their positive elements to combine with the oxygen of the ore, that is, carbonic oxide leaves carbon, and, under peculiar circumstances, hydrogen may be retained. If carbonic oxide absorbs oxygen from the ore, it leaves of course metallic iron or protoxide, and the ore, in descending, will be a mixture of metallic iron and foreign matter. If that process is not well performed, some oxides of iron will be left in the mixture. If an ore, to this extent prepared, but without any surplus of carbon, descends into the hearth, it cannot produce anything but white iron; for, if the iron is once heated to redness, and melts, it absorbs no more carbon. All the carbon required for making gray iron must be in the ore before it sinks into the hearth. For this and many other rea-

sons, we are forced to assume a surplus of free carbon in the gas mixtures of the blast furnace—carbon, if not chemically, at least mechanically, mixed with the gases, and so finely diffused that it can penetrate into the pores of the ore. If we adopt this theory, that is, the presence of free carbon, we can account for many apparent irregularities in furnace operations for which we cannot account on the simple assumption that the gases ascend in their constitutional form. By adopting this theory, we account for a circumstance otherwise incomprehensible, that is, the great influence exerted by the pressure of the blast; for if nothing else than carbonic oxide is needed, almost any pressure, even the weakest blast, will accomplish all that is desired. But we know, by experience, that the strongest blast which a given kind of fuel will bear advantageously is the most profitable. It appears, from this, that the blast works mechanically as well as chemically, in the destruction of coal; and that a certain power will produce particles of coal of a size best calculated to penetrate the pores of the ore. If these particles are too large, they cannot reach the interior of the ore, and the iron will be white. This may be assigned as the reason why a particular pressure of the blast is required to produce gray metal. If the blast is too weak, it may produce white iron from deficiency of carbon in the ore; and if too strong, the consequences are equally injurious. Such an admixture of free carbon will be, of course, uniformly diffused among the gases, and penetrate the porous ores more readily than even the gases themselves, on account of the superior affinity of carbon for oxygen.

A further evidence of the agency of free carbon, in the smelting of gray iron, is in the fact that compact, close ores, of whatever chemical composition, will not produce gray iron. Should an atmosphere of carbonic oxide, or even carbon in any other form, alone be needed to make gray metal, there would be no difficulty in manufacturing iron from any kind of ore. But this is not the case. From compact specular ore, magnetic ore, the carbonates, and ores too hard burnt, we cannot make

gray iron, whatever amount of coal we employ, and whatever kind of blast we use. A certain aggregate condition of the ore is, under all circumstances, required for the manufacture of gray metal; and this is an open, porous condition. We find that pieces of ore taken from the furnace when in good condition are, towards the boshes, of a black, and, higher up, of a brown color. An analysis of such ores has never been made; such an analysis would, of course, be attended with great difficulties; but if the composition of the ores, in their gradual descent from the top to the bottom, were fairly tested, a great accession to our knowledge would be realized.

The operation in a furnace is, then, as follows: In the upper part of the stack, the water of the materials is expelled, hydrogen from the coal is driven off, and the porous ore is, to a greater or less degree, saturated with carbon, by means of which the carbonic oxide serves to reduce a part of the ore to protoxide. The ore, in this condition, will appear, before entering the crucible, like a brick which has been exposed to the interior heat of a charcoal kiln or a coke oven—a mixture of iron ore, foreign matter, and perhaps a little carbon. This applies to cases in which the furnace operations are in good order, and in which gray iron is manufactured. All circumstances which interfere with the regular course of this work contravene favorable results, particularly in relation to the quality of the metal.

The conditions under which such a state of things may be expected, are, a porous and dry ore, a blast neither too weak nor too strong, and a low temperature in the upper parts of the stack. A high temperature is not sufficient to produce a combination of iron and carbon, at least when the iron is once in a liquid state. On the other hand, if the metal is liquid, it is difficult to separate carbon from it. If too much hydrogen is present, it is not entirely expelled until the materials are very low in the stack; but then it has sufficient time, on its way to the top, to combine with some of

the oxygen of the ore, even with the oxygen of the silix, or other oxides. We invariably find that the iron made under such circumstances is bad ; for, where hydrogen exerts any action upon ore, it deprives it of its oxygen, and thus destroys that affinity for carbon necessary to make gray metal. The best means of obviating this influence of the hydrogen—at least, the best method of making it as little dangerous as possible—is to employ low stacks, wide throats, and an abundance of strong blast ; or, if foundry metal is to be made, hot blast. Narrow tops and weak blast will not answer for bituminous fuel. We may expect to find bitumen or hydrogen in imperfectly charred wood, in soft, half-burnt coke, or in anthracite of bituminous character. Under all these circumstances, we can most effectually work with a wide tunnel head, even though the other conditions cannot be complied with. A narrow throat will expose the ore, in its almost raw state, to the influence of the hydrogen ; and in that condition, without any carbon to protect the ore, the mischief is consummated before the ore is fairly in the furnace. We will endeavor to make this subject clearly understood. Fig. 98 represents a furnace with a narrow top, examples of which we have frequently seen. The arrows indicate the current of the gases. We may here very easily perceive that the heat and action of the gases on the ore are to a great degree lost ; for it is evident that the coal will be pressed towards the lining, and that the heavier ore will remain in the centre. It is reasonable to suppose that the gases, instead of winding themselves through the close, heavy ore, will choose the easier passage through the coal. Their action upon the ore is confined to the short, narrow passage in the throat. Narrow tops, weak blast, and high stacks may answer for good, coarse fuel, and for open, porous ores, which are not loamy ; but, in all other cases, they answer imperfectly. Where well-burnt or open ores, and dry and well-charred fuel, are available, it is advisable to have wide throats, strong blast, and stacks that are not too high. In cases in which the best materials are not at

our service, or in which they are too expensive, we should use all the means to arrive at favorable results which circumstances may afford us.

The above principles are not deduced from theory: the facts on which they are based were observed prior to the existence of the science of the blast furnace, as the following considerations will establish:—

We find that in Sweden, where magnetic ores are smelted, as well as in Russia, and at the furnace at Cold Springs, N. Y., wide tunnel heads are employed. We allude only to those establishments in which the business is in so high a state of cultivation as to provoke imitation. At these places, we find not only the manufacture of a superior metal, but a remarkable reduction in the consumption of fuel. In Styria, Western Germany, and at some establishments in France, the very difficult sparry carbonates are principally smelted. These carbonates are never perfectly oxidized. Wide tops are employed at these places, which are celebrated on account of the small amount of fuel consumed. In our own country, scarcely any of the refractory ores are smelted; and at a few furnaces in New Jersey, New York, and the Eastern States, where they are used, mixtures are, to a greater or less extent, worked; and the ore charges are brought to a medium proportion of the magnetic and peroxide ores. We find an exception to this at Lake Champlain; but of this locality we shall speak hereafter. If we apply the above principles to the fuel, we find that some Russian furnaces, employing raw wood, make use of very wide tops, even from five to six feet square, and work with very strong blast, generally with but one tuyere, and with the exclusion of hot blast. Some French and German furnaces, employ either red coal or kiln-dried wood successfully, have been compelled to make use of wide tops and strong blast. Of the extent to which experiments with wood in furnaces have succeeded in the United States, we have no satisfactory information: but we are inclined to believe that, in an economical point of view, such experiments would fail; for there are few localities where both ore and fuel are

found in proper condition. Economically, open, porous oxides work better with charcoal than with wood. Refractory rich ores can be smelted with wood.

Anthracite furnaces require wider tops than coke furnaces; while the latter require far wider tops than charcoal furnaces. This width of the top may be considered the most essential improvement on the blast furnace which is supplied by anthracite coal. The height of the stack in anthracite is much less than in coke furnaces; and somewhat lower than in charcoal furnaces. Relatively, anthracite furnaces vary from thirty to thirty-five feet in height; charcoal furnaces from thirty to forty feet; and coke furnaces from forty to sixty feet. The width of the tunnel head varies, in the United States, considerably. In Pennsylvania, Ohio, Kentucky, and Tennessee, the width of furnaces at the boshes is nine, and often ten to twenty feet, and at the top from eighteen or twenty inches to six feet. The Cold Spring furnace measures at the boshes nine feet, and at the top thirty-two inches. Here the proportion is eleven feet at the boshes to one foot at the top. The dimensions of charcoal furnaces, in Europe, which smelt refractory ores are generally in the proportion of five feet at the boshes to one foot at the throat; frequently in the proportion of four to one. In coke furnaces, the proportion of the horizontal section of the boshes to that of the top is seldom less than four to one, though sometimes even 2.5 to 1.

In anthracite furnaces (in 1850), the diameter of the throat was six feet, and that of the boshes twelve feet; that is, in the proportion of one to four. But sometimes the boshes measured thirteen, and the tops eight feet square; in this case, we have the proportion of two to one. When we take into consideration the small height of the stack, and the strong blast which is applied, we shall find that this arrangement in anthracite furnaces is, in an economical point of view, very favorable; for, instead of retarding, it facilitates the vent of the gases. Narrow tops answer where loamy ore and soft coal are used; but in such cases if we expect favorable results, we should employ weak blast and high stacks. But

these conditions can be observed only where coal and labor are cheap. If we are in doubt concerning the proper dimensions of a furnace, our best course is to commence with a comparatively low stack, wide throat, and with as high a pressure in the blast as the fuel will possibly bear.

The foregoing demonstrations are designed to suggest the method of producing an excellent quality of metal. It is evident that the ore should be so prepared in the upper part of the furnace that it may be brought into the crucible in the best possible condition for producing the best metal which circumstances will permit; for we cannot expect to make gray iron from raw magnetic ore, from clinkers of ore burnt too hard, or from forge cinders. But though we are unable to smelt gray iron of good quality from these materials, nothing should prevent us from endeavoring to make the best use of the stock at our disposal. If, by means of scientific knowledge and industry, we obtain a cheaper stock, or one of better quality, we should not refuse useful material, simply because our furnace is not prepared to receive it.

If one of the conditions of success, in blast furnace operations, is that the ore should be properly prepared, that is, saturated with carbon before it reaches the hearth, or arrives at the melting heat of iron, it is, of course, a question of great importance, what kind of ore, and what composition, are best adapted to receive the carbon, and to retain it. It is easily understood that compact ores, that is, ores of great specific gravity, even if they are peroxides, and unburnt magnetic ores, spathic or argillaceous carbonates, are not well calculated to absorb carbon. Silicates or aluminates should not be smelted, for these ores are so compact that no carbon can penetrate them. The question is not so much one of chemical composition, as of mechanical or aggregate form of the ore. Such a form is the most easily produced in the peroxide; for, under most conditions, this oxide, if rubbed, yields an impalpable powder; even when in compact masses, its powder is, of all others, the finest. We roast the magnetic ore to open crevices; roast the

carbonates to expel the carbonic acid gas, and open the pores; and burn hydrates to evaporate the water belonging to their chemical composition, and thus make room for carbon. We endeavor, in roasting, to raise the oxidation of the ore to a peroxide; with the specific object of increasing the affinity of the ore for carbon, or carbonic oxide. If the ore absorbs more carbonic oxide in one instance than in another, and if the composition of the gas, that is, carbonic oxide and free carbon, is the same in both cases, then the greater the amount of oxygen it contains, the greater will be the amount of carbon which will condense upon and penetrate the ore. For these reasons, roasted and oxydized ores are required in the manufacture of gray iron. This theory is in perfect harmony with experience; and a practical iron manufacturer will find no difficulty in arriving at evidence from facts within his knowledge.

Ores are, in most cases, not only composed of iron and oxygen, but are a compound of oxide of iron and more or less foreign matter. The mixtures of oxides of iron and foreign matter are innumerable; still, where this mixture takes place beyond a given degree, the compound ceases to constitute an iron ore. But the quality rather than the quantity of foreign matter in the ore determines this question, as we shall presently see. Nevertheless, a mineral which contains less than twenty, certainly not less than sixteen, per cent. of iron, is not usually considered an ore of iron. Silica, lime, and clay are the common admixtures. Other ingredients, such as magnesia, manganese, and titanium, whatever influence they may have in particular cases, may, in ordinary investigations, be neglected.

The next important question is, what influence will any mixture of foreign matter have upon the iron ore, so far as the absorption of carbon is concerned? To answer this we would simply say, that, according to experiments in the laboratory, clay allows of the greatest affinity for carbon; next in order is silica; and then lime. This classification, however perfectly true in experiment, is apparently not confirmed by practical results. But when

we take into consideration that the mechanical form of the matter is the cause of this difference in the results arrived at by experiment and practice, this apparent exception to experiment is explained. Iron manufacturers generally consider calcareous ore the most favorable of all ores for the manufacture of gray or foundry metal. Clay ore, and then silicious ore, comes next in importance. But we should be cautious how far we base practical results upon this experience, for it frequently happens that the theory which we have deduced from practice fails; and from this failure great losses ensue. The above practical rule is applicable only where the lime or calcareous ores are, as is generally the case, already mixed with foreign matter, and where silicious and argillaceous ores are in their purity. Experiments, practically confirmed, made by Mushet, and related in his papers on iron and steel, clearly prove that iron-clay has the greatest affinity for carbon; next to clay comes silex, and then lime. A low temperature and very little fuel will revive iron from a mixture of clay and oxide of iron; but all the iron the mixture contains will not be revived, because clay is infusible by itself, and retains some particles of iron, and of course carbon. The iron is retained as an element, or radical, in an alkali. A stronger alkali is necessary, by combining with the clay, to thrust the iron from its hiding-place. This affinity of the carbon and iron for the clay might be dissolved, if the aggregate form of the clay would permit the formation of larger globules of iron; for these, following the law of gravitation, would separate in spite of affinity. Nearly the same thing happens with a mixture of silex and oxide of iron, with this difference that the silex does not absorb carbon so readily as it does clay, and does not revive iron by so low a temperature, and with so little fuel. But if no alkali combines, at the proper time, with the clay or silex, neither would yield all its iron, even though revived and carbonized. Of these earths, lime is the very last which absorbs carbon and revives iron; but then it precipitates all its iron at once, because carbonate of lime with the silex is fusible by itself, and will, when

concentrated into a melted slag, squeeze or drop the iron out.

Agreeably to these principles, clay ores will require a low temperature in the upper part of the stack. We should endeavor to extend this temperature to as low a depth as possible. This will prevent the precipitation of iron before any lime is sufficiently heated to receive the clay, and will consequently prevent the combination of iron and clay into an aluminate, from which it is difficult to separate the iron. Silex or silicious ore is very nearly of the same character, but will permit of a higher degree of heat, without much danger. With calcareous ore we may raise the heat as high in the stack as we please, without endangering the result. These principles, deduced from theory, coincide exactly with experience at the furnace. If we smelt pure calcareous ore—not what is sometimes called the limestone ore, for this is generally a precipitate of iron upon a limestone bed, and contains very little lime—we need a strong heat in the furnace, and an abundance of fuel. The reason of this is that the upper heat of the stack and the action of the reviving gases are entirely lost, for lime and limestone ore condense little or no carbon. We thus find that pure calcareous ores are not the most profitable; and we shall make a better use of the fuel, if along with it we mix silicious and clay ore. In this way, we shall not only derive greater profit from the gases, but a lower temperature of the stack will enable us to secure many advantages. Foreign admixtures are thus shown to be unaccompanied with injurious results; but this principle cannot be extended to a chemical admixture or combination.

From these statements, it is evident that a proper mixture of different ores will be beneficial, so far as the use of fuel is concerned; and that the more closely and intimately the ores are mixed, the better will be the result. A medium temperature is a security that the furnace will work well, and guarantees economy of fuel and a favorable product. Where proper mixtures of foreign matter are already contained in the ore, the most

profitable work may of course be expected. Ores of this kind are frequently met with in the coal formations, as precipitates upon limestone or clay. This is the case at Huntingdon County, Pa., and at other places. The out-crop ores of the anthracite coal series, as well as the Western coal fields, exhibit generally this composition. A great majority of the Western furnaces, such as those at Hanging Rock, and at many places along the Alleghany River, work these ores.

We have, we think, sufficiently proved that the aggregate state—the physical composition—of an ore has an important bearing upon the operations of a furnace; but it is obvious that the chemical relations must be still more important. To arrive, by the surest and shortest method, at a clear and comprehensive conclusion, we shall describe the particular behavior of each kind of ore.

If we charge a furnace with unroasted magnetic ore, the ore will sink with the coal charges unaltered until it arrives at a certain point, when it will melt into a more or less liquid slag. This slag will pass through a column of hot coal, when a portion of the iron will be revived; another portion will combine with silicious and aluminous matter, and form cinder, which is lost. The iron which results is not gray. The carbonates, and other compact and heavy ores, exhibit the same peculiarities. If limestone is charged along with the ore, a large quantity of iron will be revived; still, a great deal of iron is lost. In no case should we expect gray iron; for, though it should happen that some carburetted iron has been formed in the furnace about the hearth, yet so long as the cinder contains protoxide of iron, the carbon from the gray iron in the hearth will be absorbed, and iron from the cinder revived. The latter is the case when the ores contain foreign matter; but, if the ores contain little or no foreign matter, there will not be sufficient cinder even to protect the iron from the influence of the oxygen of the blast. In this case, the iron must of course be white. The ores may be compact or porous. The result is, in both cases, the same;

for, if carburetted iron is formed in the upper parts of the furnace, without a protecting cinder, it will be white before it arrives in the crucible. Satisfactory results cannot be obtained from these ores, unless we have a warm furnace, and unless the heat is raised to a considerable height in the stack.

If an iron ore contains foreign matter, and if this matter is a single earth, in itself refractory, the mechanical form of the ore may be the most advantageous; but the metal which results will always be white. When a furnace is charged with clay ore, the ore will, in its descent, absorb and condense carbon. When the carburetted metal arrives within reach of the blast, the carbon will be absorbed by the carbonic acid, and the iron will arrive whitened in the crucible; the remaining iron yet in the clay will be highly carburetted; but the clay cannot melt and protect the iron. The result is white iron; and, if no limestone is present, an aluminate of iron, as cinder. What we have stated is applicable, in most respects, to silicious ore; also to calcareous ore, with this difference, that, in the latter case, no protoxide of iron is needed to flux the cinder. If, by applying an excess of fuel, we try to revive all the iron from the ore, or, at least, to revive it in greater quantity, then, with clay as well as silicious ore, we receive a tenacious cinder in the hearth below the tuyere, which retains the globules of iron on its surface. If a dark gray carburet comes down, it will soon become white iron within the influence of the blast. Should the cinder not be sufficiently liquid to permit the iron to pass through it, the iron will oxidize, and form protoxide combining with the cinder, until it effects its escape. The necessity of fluid fluxes is thus clearly seen.

If we charge a furnace with poor ore, with an admixture of a refractory character, in a state of fine, impalpable aggregation, as is generally the case with clay ores, and particularly the case with some silicious ores, the iron will be revived by a comparatively low temperature, and for this reason will combine with a large amount of carbon. But this carbon cannot be retained,

if the original globules of iron are exposed to the direct influence of the blast ; for these grains of melted metal are so small that they can pass through only a very liquid cinder. Should the cinder not be sufficiently liquid, the resulting metal will be white. This is another reason why the smelting of gray iron from clay and some silicious ores is so difficult. To arrive at desirable results, it is advisable to have fine clay ore along with silicious ore. This ore revives a portion of its iron by a low heat, and is, of course, highly carburetted. If the iron produced descends, and finds, on its way, silicious ore ready to deliver iron, it will combine with it, and form a larger mass. If this combination, in its further descent, comes in contact with a calcareous ore, which, under ordinary circumstances, would not liberate iron, the carburetted iron of the clay and silicious ore will draw with it a portion of iron from the calcareous ore ; this augmented combination will resist the influence of the blast, and by its ponderability will work, with greater readiness, a passage through the melted cinder below the tuyere. The remaining iron in the clay ore, which, in most cases, amounts to half the original quantity, will be inclosed in the unaltered piece of ore until it arrives in the hearth below the tuyere. If, at that point, it meets with silicious or calcareous ore, both of which are in the same condition, the different earths, being in a high temperature, will combine, form a liquid cinder, and drop the iron out. The iron, having been protected from the blast by the refractory cinder which surrounds it, is now perfectly protected against the blast by the melting cinder, composed of the foreign matter of the different ores.

The case which we have described may not, in practice, happen in all the fulness and minuteness of this description, for there are few clay ores which do not contain a portion of silex ; few silicious ores which contain no lime, or magnesia, or clay ; and scarcely any calcareous ore which does not contain a portion of clay or silex. The above is a theoretical case, brought forward merely to illustrate a principle. There is a possi-

bility that similar coincidences may exist in practice ; but they can happen only very seldom.

Experience has clearly proved that, of all ores, those which flux themselves are the most profitable. That is to say, any mixture of ore, or any individual ore, which produces good metal, and a liquid cinder free of iron, is more profitable than those ores which require the interference of fluxes not containing any metal. What constitutes a good cinder, we shall investigate hereafter. We shall confine our attention at present simply to the iron, and to the operations which take place in the furnace. If clay ore, as already explained, yields a portion of its iron very readily, we may infer that this is grayer than any other portion, because carbon combines more easily with iron at a low than at a high temperature ; but this carburetted iron is destroyed on account of the refractory quality of the clay. If the clay, mixed with the ore, should contain a portion of lime and silex, its refractory character would be diminished, and the carburetted iron in the inside of the fragment of ore would be more perfectly protected against the influence of the blast. If the carburetted iron thus protected should find an alkali in the cinder, below the tuyere, waiting to receive the foreign matter, it will descend with scarcely any loss of carbon. From this it is evident that we may expect gray metal from mixed clay ores, if lime or any alkali is present in the hearth ; but not otherwise. If the foreign admixtures of the ore are not of such a nature as to form a liquid cinder, the cinder must be made sufficiently liquid by the addition of flux, or by the loss of a portion of iron.

In reality, there are few purely clay, silicious, or calcareous ores. The native deposits are, to a greater or less extent, compounds of iron ore, and of various foreign matters ; still, the clay and silicious ores predominate. Calcareous ores are not generally met with on this continent. Therefore, in most cases where iron is smelted, an admixture of limestone, instead of calcareous ore, must answer our purpose. A mixture of lime and iron is always useful ; for pure lime will sink into the hearth,

and remain in lumps until slowly dissolved by descending clay or silex. If lime contains a quantity of iron, or other foreign matter, it will melt above the tuyere, leave the hearth free of any obstruction to the descending iron, and give the blast free play at the coal; therefore, a limestone which is not refractory is preferable.

The above process takes place when silicious and clay ores are to be smelted, and when the flux is limestone, but let us consider the case in which calcareous ore is to be smelted, and fluxed with silex or clay. As mentioned above, calcareous ores require a strong heat, and permit the raising of the heat to an uncommon height in the stack. On that account, more fuel is consumed for these than for other ores. If calcareous ore is smelted by charcoal, which contains but a small quantity of silex, the ore will melt into a slag, as in the case of the magnetic ore, and in descending will lose some of its iron. If the heat is strong, and if more iron is separated, some of the lime will either be blown off at the tunnel head, which we often observe issuing in a white, fine dust, or will combine with the silex of the coke or stonecoal, and descend to the hearth. Under all circumstances, a part of the lime will descend below the tuyere, and if it does not find silex or clay in the cinder, it will attack the hearthstones; and by this means the lime is saturated with clay or silex, becomes liquid, and is in a condition fit to be discharged. In this case, the iron is of no use in fluxing the limestone, for, at the high temperature of the furnace and hearth, all the iron is precipitated; and if there is no carbonic acid in the lime, or if no clay or silex is present, no combination between them is possible. Calcareous ores should be fluxed by clay or silex. Pure sand and fire clay cannot be of any service; they do not melt; they sink gradually into the hearth; and if any iron from the calcareous ore is liberated, it has a tendency to combine with silex or clay. The first chance of receiving oxygen affords an opportunity of forming protoxide of iron, and silicates or aluminates of iron. Such disturbances happen frequently with calcareous ore. An excess of lime in the ore is, to all appear-

ances, not sufficient to precipitate the whole of the iron, because the blast cools off the hard, unmelted clinkers of clay and silex around the tuyere. If, in such cases, we select a clay which contains iron, or any matter capable of melting the clay at a low temperature, then such a flux, melting at a high point in the stack, will meet, in its descent through the hot fuel, the heated calcareous ore, and, combining with the lime, liberate the iron, which is then at liberty to descend. A part of the iron will be retained by the imperfectly melted lime and flux; but, on coming in contact with the more concentrated heat of the hearth, it will be separated.

From the foregoing demonstrations, we are enabled to draw conclusions relative to the economical working of the ores. It follows, from what we have stated, that clay ores are, of all ores, the most profitable, because of the facility with which they absorb carbon, and because of the low temperature at which they precipitate iron; but the refractory character of their admixtures prevents us from deriving those advantages from them which, under other circumstances, they would furnish. Silicious ores do not absorb carbon so readily; but the foreign matter which they contain is more inclined to form liquid compounds with lime or iron, and to liberate the revived iron. On this account, they are more manageable than the clay ores. Notwithstanding the tendency of silicious ores to smelt white iron, the fusibility of their admixtures, in contact with alkalies, gives them precedence over the clay ores for the smelting of gray or foundry metal. Calcareous ores do not appropriate carbon, if the amount of lime in the admixture is large; but, if it is small, they make a carbon iron like the pure peroxide of iron. However, they will not retain it absorbed, because the iron revived is not very liquid. The carbon is retained in the ore until exposed to the influence of blast, when it disappears. It is a well-known fact that ores containing much lime in admixture do not produce gray iron with facility, and consume more fuel than any other ores.

What is the cause of the difference in the capacity of

matters to absorb and retain carbon? For the solution of this question we must refer to chemistry. But so important is this subject to the iron manufacturer, that we shall offer no apology for directing, as briefly as possible, his attention to it. Observation has unquestionably proved that clay possesses the power of condensing carbon in the highest degree; and that there is scarcely any matter so little disposed to absorb and retain carbon as lime. As a carbonate, lime will absorb carbon, but not as burnt or quicklime. This may be caused, in part, by chemical affinity; but there is no question that it is, to some extent, caused by the mechanical form of the particles of matter; otherwise the difference between clay and silex would not be so great. There is no doubt that the same power which retains the carbon retains the iron. The particles of clay are very minute; so also are the particles of the oxide of iron mixed with clay. When carbon penetrates the pores of such a mixture, and heat is applied, a part of the metal is retained in the interior of the ore fragment. The particles of silex are coarser than those of clay; and if the affinity of silex for carbon were so great as that of clay, it could not retain so much iron as the latter, because of its coarse grain. From this quality, added to the other facilities which it possesses of reviving iron, it may be considered a more profitable ore than the above. Lime, in its aggregate form, is very fine-grained; but it does not absorb any carbon, and for that reason the iron is refractory, that is, it cannot separate from the lime at a low heat. The iron is not sufficiently liquid thus to separate, and is retained until the lime, becoming fluxed, leaves it.

For these reasons, we are convinced that rich ores consume a great deal of fuel, and, on this account, are not so good as some poorer ores. If the disadvantages of their use are not compensated by cheap fuel, and by the production of a good quality of metal, it is not advisable to smelt them by themselves. Calcareous ore is equally expensive, so far as the consumption of fuel is concerned; and, if smelted by itself, is little apt to pro-

duce good iron. The same remark applies, to nearly the same extent, to silicious ore. Clay ore, if poor, would not produce any iron, if smelted without fluxes. It thus clearly appears that no iron ore, of whatever description, is, melted by itself, so profitable as it would be when mixed with other ores.

The iron which, in the clay ore, is so readily carbonized, will not separate from its foreign matter until that matter is absorbed by another element which has the power of liquefying it. This is also the case with silicious and calcareous ores. Rich ores do not smelt well, because their pores have no opportunity of absorbing carbon at a low temperature; therefore, these ores are not prepared for reduction when they arrive in the neighborhood of the tuyere. The rich ores receive and absorb carbon, and produce iron, by flowing in a semi-liquid slag through a column of hot coal of greater or less height, according to the quality of the ore. These considerations lead us to the construction of the interior of the blast furnace, and to the development of the principles by which its form and dimensions are determined.

Applying these principles, we should build a furnace without a hearth, that is, by sloping the boshes down to the tuyere, in case it is our intention to smelt rich ores; and we should make a partial or complete hearth above the tuyere, according as facilities presented themselves of mixing the rich ore with poorer ores of the proper kind. If we could bring the mixture to an advantageous standard, we should employ a narrow or high hearth, with the object of economizing fuel, of obtaining a better yield from the ore, and of smelting gray iron. Any alterations required should be made in conformity to these considerations. If we arrive at conclusions too hastily, we shall have the mortification of finding that our anticipations will not be realized, and we shall be under the necessity of returning to the original form. The form we have suggested, that is, a furnace without a hearth, owes its importance to the necessity which exists of raising the temperature of the whole stack to a high

degree, because, unless there is a high column of hot coal, the melted ore will not be affected by carbon. This rule is also to be applied to calcareous ore. For silicious and clay ores the hearth may be high, and the boshes flat. These ores absorb carbon in proportion to the coolness of the upper part of the furnace. When, after being saturated with carbon, they arrive in the narrow part of the hearth, the intense heat of the crucible will melt the iron and the foreign matter almost at the same moment. If the foreign matter is fluxed, the iron will thus be precipitated in the shortest possible manner.

From these investigations we have arrived at the conclusion, theoretically, that no ore is perfect. This conclusion is confirmed by practice. The magnetic are not the most profitable ores, because of the amount of fuel they consume. The same remark applies to the compact oxides, to calcareous ore, and to silicious and clay ore. For this reason, the latter do not yield well. By mixing the various kinds of ore, the virtues of one will counterbalance the imperfections of another. The desideratum is to find a proportional admixture united in a native ore. In practice, the ores are mixed in a certain ratio with this object in view. This conclusion leads naturally to the inquiry concerning the different portions of each kind of ore, and, consequently, to the constitution of cinder.

It will be clear, after reading the above, that the knowledge of the composition of the foreign matters in the ores, which, when melted together, constitute cinder, and the knowledge of the circumstances under which the most favorable results can be obtained, are highly valuable. Iron, under certain conditions, can be melted; if protected against oxygen, it is unaffected by heat. Like other metals, it is more fusible when an alloy is combined with it; it is most fusible when combined with phosphorus, sulphur, or carbon. The latter element is preferable, because phosphorus and sulphur are considered injurious to the quality of the metal. We are thus led to conclude that, if iron could be combined with carbon under all circumstances, it would be

equally liquid, no matter from what kind of ore it has been smelted. This conclusion is true ; but we have seen that some ores will not make carburetted iron at all ; and that others, which make it in abundance, cannot precipitate all their iron, on account of the refractory quality of its admixture. If an admixture of ore is just as fusible as the iron itself, the iron and foreign matter will separate spontaneously. This is the principal, the surest and most profitable way of smelting ; and this is to be our aim.

From this, it is apparent that the appropriate way of proceeding will be, so to combine different ores that the iron and foreign matter will melt at the same moment, or, what is the same thing, at the same temperature.

If such a mixture is porous, it will absorb carbon, and offer a chance of smelting by a lower temperature. If its composition is favorable to the absorption of carbon, the only difficulty which remains is the production of a cinder quite as liquid as the iron. This is performed less easily than we should at first conceive ; for, if we compound the material for the making of cinder, it is only under certain conditions that we arrive at the best results ; and these conditions are, to a great extent, limited to local elements.

Mr. J. H. Alexander, of Baltimore, tells us, in his *Report on the Manufacture of Iron*, that the difference in the consumption of fuel varies according to the fusibility of the ore, and it appears from this table that the richest ores consume the most fuel], which, however, may be the consequence of certain conditions of the ore and limestone used, as we shall see under Charges, etc., in a future chapter, and may have no essential relation to mere richness of the ore. [We extract the following table from his Report :—

Table showing the probable consumption of charcoal per 100 parts of crude iron, with ores of different sorts.

Denomination.	Proportion of metal per 100 ore.	Charcoal consumed per 100 metal.
Fusible ores—yielding	{ 25 to 30	66 to 90
	{ 30 “ 35	90 “ 110
	{ 35 “ 40	120 “ 130
Ores of mean fusibility—yielding	{ 30 “ 40	110 “ 140
	{ 40 “ 50	140 “ 180
	{ 50 “ 60	180 “ 220
Ores hardly fusible—yielding	{ 30 “ 40	160 “ 200
	{ 40 “ 50	210 “ 250
	{ 50 “ 60	250 “ 300

These results, applied to tons of iron and bushels of coal, would give us from 100 to 440 bushels of charcoal per ton of iron.

To understand this table properly, we may remark that the above amount of fuel will be consumed, if we manufacture gray iron. The rich specular ores, the spathic ores, &c., do not consume much fuel, if we are satisfied with white metal, and suffer a portion of the ore, in combination with the foreign matter, to form cinder.

The relative degree of fusibility of the cinder is, however, the main point to be sought. Where the cinder is too thick and pasty below the tuyere, the iron globules cannot pass the blast without injury; where it is too liquid, it will leave the iron too soon, and thus expose the metal to the influence of the blast. The most desirable condition is that in which the cinder and iron have the same fusibility, and arrive together in the hearth before either is sufficiently heated for melting. If one should be more fusible than the other, that one is the cinder. But to secure this high state of fusibility, and at the same time to smelt gray iron, is possible only under very favorable conditions.

In practice, we can produce almost any degree of fusibility we desire by means of lime, clay, and silex. All other materials which serve as fluxes are in quantities too small to be entitled to notice, and impracticable for

general application : such as soda, potash, manganese, and magnesia. We shall cursorily notice these materials, as they are occasionally employed, and as they will assist in the explanation of the principles of fusibility.

Soda is the most powerful solvent of silex or clay ; after this comes potash, then lime, then magnesia. The alkaline earths, as baryta, strontia, lime, magnesia, and alumina form with silex very refractory compounds. If but one of these earths is combined with silex, the compound is scarcely fusible in the strongest heat of the blast furnace. Such combinations exist as native deposits. Fire-clay is a compound of silex and clay, a silicate of alumina ; it will resist a very strong heat. Soapstone is a silicate of magnesia, and also bears a very strong fire ; but an excessive heat is not required to melt a mixture of pounded fire-clay and pounded soapstone. This principle is the leading feature in the art of mixing ores.

We see here that silex, in combination with clay or magnesia, will not melt ; but a mixture of a given amount of alkali, magnesia, and clay, with a given amount of silex or acid, is fusible. If to the above two silicates we add a third silicate in itself either infusible or strongly refractory, say silicate of lime, the whole mixture is melted at a lower temperature than that at which any two of them will melt ; and if we still add a fourth silicate, the fusibility is below the mean temperature of the whole mixture. That is to say, if the first silicate will melt by itself at 100° , the second at 90° , the third at 80° , and the fourth at 20° , the whole, mixed together, will melt below a temperature represented by the sum of all the temperatures added together, and divided by the number of primary silicates. Thus, $100^{\circ} + 90^{\circ} + 80^{\circ} + 20^{\circ} = 72^{\circ}$ would be the mean ; but the composition would melt below the mean temperature.

The fusibility of a binary compound, that is, a single base and silex, depends very much on the degree of chemical affinity of the two elements. As we have before stated, soda and silex have the greatest affinity.

Then follow potash, baryta, strontia, magnesia, lime, and lastly clay, in the order of affinity. That is to say, a mixture of one pound of soda and one pound of silex will melt at a lower temperature than a mixture of one pound of clay and one pound of silex. If the amount of one element increases too much, proportionally to the other, the fusibility decreases. There is a limit in the relative proportion of matter at which the greatest fusibility is produced. The fusibility of a mixture of baryta and silex ranges between thirty and seventy per cent. In cases where the silex is less than thirty, and more than seventy, per cent., the mixture is equally infusible. So far does this law extend, that the most fusible compounds permit the greatest range, and the least fusible are confined to the narrowest limits. Potash is fusible by itself, and a mixture of ninety-nine silex and one soda or potash is not infusible; while the fusibility of a lime silicate ranges only between twenty-five and forty-seven per cent. of lime, and a strontia silicate is confined to but one proportion, that is, forty-five strontia and fifty-five silex. Silicates of alumina and of magnesia are not fusible at all in the heat of a blast furnace.

The alkalis proper and the alkaline earths are not the only elements which form fusible compounds with silex. The metallic oxides, in obedience to the law of affinity, possess this attribute in a higher degree even than the alkaline earths. The oxides of bismuth, lead and iron especially, form fusible compounds; of these, however, the silicates of iron alone interest us. The protoxide of iron forms with silex a very fusible compound, which reaches from 40 to 82 per cent. of protoxide, and is not far behind the lime. Peroxide of iron silicates are almost infusible. Copper, zinc, and tin silicates are scarcely fusible.

Amongst the electro-positive elements (the bases) of the above enumerated compounds, we should pay particular attention to the behavior of clay under different circumstances. Alumina is not a strong alkali, but possesses the remarkable property of becoming an alkali

where an alkali is needed, and of forming an acid where there is a surplus of alkali in the composition.

The tendency of the alkalies or their carbonates to dissolve metallic oxides is a fact worthy of special notice. Six parts of carbonate of potash dissolve one part of iron protoxide, and carbonate of iron is still more soluble. The carbonates of lime and magnesia dissolve protoxide and carbonate of iron very readily. Other metallic compounds of that kind are of no interest to us.

Silicates, or the melted and liquid compounds of alkalies and silex, possess the property of dissolving metallic oxides, and often to a large amount. Such solutions are, to a greater or less extent, colored; sometimes they are white. The protoxides of iron impart a green color to the cinder, and, if in large quantity, a black color. Magnetic oxide colors the cinder brown, and, when in large amount, black. Peroxide of iron imparts a dirty yellow or reddish color to the cinder; it is but little soluble. Carbonate of iron imparts to cinder a white or yellow color. Colors imparted by other matter will be mentioned in another place.

It may be mentioned that free lime, or a surplus of lime in cinder, possesses the property of absorbing sulphur. Free alumina, or a surplus of alumina if an abundance of alkali is present, will absorb phosphorus, and carry it off in the cinders. The same remark applies to lime.

After the above consideration of the general principles in the formation of cinders, we are led to inquire, what constitutes a good cinder? A positively good cinder is one which is fusible at that heat at which the iron it incloses will become liquid. The lower that temperature, the less will be the amount of fuel used in the process of smelting. From this it is obvious that the fusibility of the cinder should bear a certain relation to the mechanical form and chemical composition of the ore. An open, porous clay ore will require the most fusible cinder; and a calcareous ore, a refractory admixture. Different degrees of fusibility require distinct compositions of cinder and of iron; therefore, the cinders

from differently composed ores, and from different fuel, will require different temperatures for smelting.

The degrees of heat at which iron containing more or less carbon will melt, are not accurately known. According to our own calculations, the fusibility of pig iron is not beyond 2700° , because the fuel in the blast furnace cannot produce a higher temperature. Many able observers have concluded that the temperature exceeds that point, but that it is not beyond 3000° . We may, from these premises, conclude that the melting point of the different kinds of metal ranges between 2000° and 3000° .

In investigations concerning the fusibility of silicates, cinders, and artificial compounds, some very useful experiments have been made, from which we select the following :—

A furnace cinder, composed of silex 50, alumina 17, protoxide of iron 3, lime 30, melted at 2576° .

Another cinder, composed of silex 58, alumina 6, protoxide of iron 2, manganese 2, magnesia 10, lime 22, fused at 2500° .

The latter is a very complicated cinder, and ought to melt at a somewhat low heat, but its composition is of a very refractory character, as may be observed from the large amount of silex it contains. These cinders will bear comparison with the anthracite cinders of Pennsylvania.

A greenish, rather dark cinder, from a charcoal furnace, melted at 2498° .

We shall have an opportunity of presenting further analyses of cinder in another chapter. It ought to be remarked that in forming artificial cinder from very finely powdered elements, the temperature at which the smelting begins is always from 500° to 700° higher than that at which the cinder is kept liquid. The truth of this remark is sufficiently proved by the refractory character of the elements. Hence results the necessity of reducing the size of the materials, as far as practicable. Where the elements of the ore are very refractory, the finest division is required ; but where the elements of a

very liquid cinder are contained in the ore itself, the breaking of the ore requires no special attention.

It is very seldom in our power to select an ore, for our smelting operations, which contains in itself the elements of a good cinder. Sometimes we are enabled to mix those ores which form a good cinder, and which flux each other; but in most cases we are compelled to add a simple flux to the ore we have selected. This is found to be most profitable if we are enabled to add limestone to our ore charges. The reasons why limestone is the best flux are the following: For various reasons, we generally attempt to smelt gray iron. To effect this object, it is necessary to produce, or we at least desire, a cinder but slightly more fusible than the iron itself. Gray iron is most easily produced from clay or silicious ore, or from very porous oxides. Where we have a choice between a clay and a calcareous ore, the former should be selected, for it offers greater advantages than the latter. If a clay ore is fluxed by lime, the lime will not melt in the upper part of the furnace, but will descend into the hearth in its original form, sometimes burnt into quicklime, but very often as a carbonate. Now, if prepared ore descends, the lime is ready to receive the clay and silex, and the iron is speedily separated; the whole mass in the hearth, hot coal and lime, through which the ore and iron are to pass, is favorable to the reviving of the metal; and should particles of iron and foreign matter even be melted together, there is a chance that a separation will be effected. But this is not the case where calcareous ore is smelted. If the amount of lime mixed with the ore is so large as to require a flux of clay or silex (under all circumstances, clay is preferable, because it contains a portion of silex), the silicious matter will descend to the tuyere, and there wait for the lime; the calcareous ore does not melt nor yield its iron until it arrives at the tuyere, that is, if the ore contains no other matter which would make it fusible. In this case, the whole process of forming cinder is accomplished very nearly before the tuyere; while in the

former case, the process will, in most cases, commence higher up in the hearth.

We have thus endeavored to explain, in as simple a manner as possible, the theory of the blast furnace. The composition of cinder, a subject less easily understood by those who have not studied chemistry, deserves our closest attention. To bring this subject to the comprehension of all who desire information, we shall conclude this chapter by presenting a series of applications, drawn from ore analyses, contained in *Rogers's Report on the Geology of Pennsylvania*.

To convey a clear idea of the specific object we desire to accomplish, we shall insert the following analyses of furnace cinder, taken from Mr. Alexander's *Report*. We shall also attempt to reconstruct from the ores of Pennsylvania such cinders as are taken from furnaces in Europe.

	Charcoal Furnaces.							Coke Furnaces.		
	Peroxide ores.			Sparry carbonate ores.				Carbonates of the coal formations.		
	1	2	3	4	5	6	7	8	9	10
Silica	51.84	63.6	31.1	52.0	71.0	37.8	49.6	40.6	43.2	35.4
Lime	21.80	24.0	14.1	30.2	7.2	...	...	32.2	35.2	38.4
Magnesia	4.82	1.2	34.2	5.2	5.2	8.6	15.2	...	4.0	1.5
Alumina	15.21	3.8	8.9	5.0	2.5	2.1	9.0	16.8	12.0	16.2
Prot. of iron	3.73	1.7	1.0	1.6	5.0	21.5	0.4	10.4	4.2	1.2
Prot. of manganese .	1.16	3.9	4.4	4.7	6.5	29.2	25.8	...	...	2.6
Oxide of titanium .	...	...	9.0	...	...	...	...	...	...	...
Sulphur . . . . .	...	...	trace	...	...	trace	...	...	...	1.4
Phosphoric acid .	...	trace	...	...	...	...	...	...	...	...

No. 1 is an average cinder of good iron: No. 2 is derived from a furnace smelting bog ores; No. 3 from a Swedish furnace; No. 4 from France; No. 5 from Savoy, and is the result of bad work in the furnace; Nos. 6 and 7 from a German furnace—the first when in bad, and the latter when in good, condition; this furnace usually melts steel metal, from which German steel is manufactured. Nos. 8, 9, and 10 are derived from coke furnaces in Wales. The latter specimen is said to be taken

from the furnace when in bad condition ; it is from the same as No. 8.

To imitate these cinders, just as they appear in the above table, would be almost impossible. But this is not required. We can arrive at the same result by another method—a somewhat indirect one, to be sure, but still tending to consummate the desired result. There is a law of chemistry which governs the present case ; namely, that a certain amount of silex or acid requires the saturation of a certain amount of base, such as lime, or magnesia, or protoxide of iron, so that no base or acid be left uncombined. In such a neutral condition, the cinder will be most fusible. Now it matters not whether lime is replaced by magnesia, by protoxide of manganese, or by any given base ; but there should never be a large surplus either of acid or alkali in the furnace, for such a surplus will remain refractory, and finally occasion much trouble. The elements which combine to form a fusible cinder are the oxides of metals ; and the amount of oxygen in the silex or acid must be equal to the amount of oxygen in the base, or it must be present in a proportion two or three times greater, or two or three times less, than the amount of oxygen in the base ; that is to say, the one must be united with the other in definite proportions. An enumeration of the equivalents of the various compounds necessary to be taken into consideration may be found in any handbook of chemistry. In the foregoing, as well as the following demonstration, we must not be understood to say that, with the saturation of the silex by different alkalies, the degree of fusibility is the same ; but that the saturation to which we allude, is a neutralization by which a surplus either of alkali or acid is prevented.

In the above table, the average cinder, No. 1, may be considered a fair specimen for imitation. For practical purposes, it is not necessary that the equivalents should be numerically correct. A small surplus of oxygen in either respect should not be considered very injurious. Should we wish to imitate cinder No. 1 at a charcoal

furnace situated near the canal, Westmoreland County, Pa., we shall find that, at the locality, the main body of ore is of the argillaceous kind. A specimen of this ore, taken near Blairsville, exhibited, according to an analysis of Prof. Rogers, the following, composed in 100 parts:—

Carbonate of iron	. . . . .	71.19
Carbonate of lime	. . . . .	3.50
Carbonate of magnesia	. . . . .	2.72
Alumina	. . . . .	2.10
Silica	. . . . .	17.55
Water, &c.	. . . . .	2.94

We are not concerned, at present, with the iron and water, but with the other ingredients. The proportion of the silex in the ore is only 17.55; but the table above presented calls for 51.84. We must, therefore, multiply all other oxides by the number resulting from the division of 51.84 by 17.55, which is 2.9. Alumina $2.10 \times 2.9 = 6.09$, which leaves a deficiency of $15.21 - 6.09 = 9.12$ alumina. Carbonate of magnesia is composed of 44.69 magnesia and 35.86 carbonic acid. We assume it to be a subcarbonate, which is generally the case; then the amount of caustic magnesia in this specimen of ore will be

$$\left((44.69 + 35.86) : 2.72 = 44.69 : x \right) \times 2.9 = 3.77.$$

But we want 4.82 magnesia; therefore a deficiency of $4.82 - 3.77 = 1.05$ magnesia is left. Carbonate of lime is a compound of 56 lime and 44 carbonic acid. In the table, the proportion of lime is 21.80. The ore contains but 3.50 carbonate of lime; thus making

$$\left((56 + 44) : 3.50 = 56 : x \right) \times 2.9 = 5.99:$$

therefore there is a deficiency of $21.80 - 5.99 = 15.81$ lime. Taking the whole 15.81 lime, 1.05 magnesia, 9.12 alumina, a small quantity of iron and manganese is yet required. The ashes of the fuel will deliver a portion of the alkaline matter, but its quantity is comparatively small; and our labors would be unnecessarily complicated if we should take that into account. Our

next object should be to find a mineral flux which contains whatever matter we need. No useful purpose will be served by mixing the ore with another from the same neighborhood; because none can be found which contains the requisite amount of clay and manganese. In the coal regions along the canal, among the various veins of different composition, an ore may be found suitable to match the above. We select from Rogers's *Report* an analysis of a specimen found at Brighton, Beaver County. As the same strata of rock from which this specimen was taken are accessible at the Pennsylvania canal, there is a possibility that an ore like it, or similar to it, may be found in its vicinity. The Brighton ore contains

Carbonate of iron,	. . . . .	43.89
Carbonate of manganese,	. . . . .	7.20
Carbonate of lime,	. . . . .	42.51
Carbonate of magnesia,	. . . . .	3.57
Silex, &c.,	. . . . .	0.40
Loss,	. . . . .	2.43

The silex, in this analysis, may be neglected. If its amount were greater, it would be necessary to add it to the silex of the first specimen, and correct the basic elements accordingly; that is, to add to the silex of the first specimen the silex of the second, and to subtract from the lime, magnesia, and alumina, according to the ratio of the silex added.

In the above specimen, we have 42.51 carbonate of lime, which will be equivalent to $((56.44) : 42.51 = 56 : x)$
 $\times = 23.8$ lime. We have also 3.57 carbonate of magnesia, which is equal to $((44.69 + 35.86) : 3.57 = 44.69 : x)$
 and \times is 1.59 magnesia. The manganese amounts to 4.75. In comparing the whole, the result is as follows:

The analysis requires	First ore.	Second ore.	Total.
Silex	51.84	51.84	= 51.84
Lime	21.80	5.99 + 23.8	= 29.79
Magnesia	4.82	3.77 + 1.59	= 5.36
Alumina	15.21	6.09	= 6.09
Protoxide of iron	3.73		
Protoxide of manganese	1.16	4.75	= 4.75

The first may be considered an argillaceous, inclining to a silicious ore, and the second a true calcareous ore. Each of these ores fluxes the other almost completely, at least sufficiently for every practical purpose. The mixture of these two ores would work exceedingly well, and readily produce gray foundry metal; with greater facility even than the original or model cinder in the table of Mr. Alexander. But the metal thus produced would not be so strong as that smelted by the model cinder; neither would it be so well adapted to produce forge metal, because of the deficiency of alumina in the Bolivar ore. These ores should be mixed in the ratio of 2.9 of the first to one of the latter; the resulting mixture would yield 30.1 per cent. of iron, for the first ore contains 34.37, and the second 20.79, per cent. of iron.

If no calcareous ore can be found at a reasonable price, a dead flux, such as lime, should be employed. The first, or Bolivar ore, contains clay in quantity rather too small to make forge metal, but in quantity sufficiently large to produce foundry metal. If it is our design to smelt the former, an addition of clay, or of limestone which contains clay, should be preferred to pure limestone. In the regular limestone strata of that region, limestone which contains even one or two per cent. can scarcely be found; but in the shale strata of the same region, there exist small deposits of an argillaceous limestone called cement lime. From these sources, a profitable flux for the above ore may be obtained.

In Mr. Alexander's table, cinder No. 3 is taken from a Swedish furnace: this cinder is remarkable on account of the large amount of titanium it contains; titanium is generally the companion of magnetic ores. A similar ore exists at Lake Champlain in large quantities, the working of which is different from that of most other ores. We shall therefore make some remarks on this subject, for not only the Lake Champlain ores, but most of the magnetic ores of New York, Wisconsin, and Missouri contain titanium. It is said that the above ore contains 11 per cent. of oxide of titanium; this will account as well for the many difficulties encountered in

smelting it, as for the great expenses incurred in manufacturing iron from it. Titanium, or titanic acid, neither benefits the iron ore nor injures the metal manufactured from it; still, it may occasion much trouble in the furnace. It does not combine with iron, silex, lime, potash, or anything else; avoiding all connection with contiguous atoms, it associates neither with the individuals of the alkaline nor with those of the acid series. Still, there is a way of getting rid of this exceedingly troublesome substance, that is, by letting it go with the masses of cinder. Titanic acid does not melt by itself, nor with anything else. If present to the amount of ten per cent. in the ore, a neutral matter, amounting to 330 pounds, will thus exist in every ton of iron, that is, if we take only a ton and a half of ore to the ton of metal; but, on an average, two tons of ore are required to produce a ton of metal. If but a tenth part remains in the furnaces, it will speedily accumulate, and obstruct the passage of the cinder; and this obstruction no heat can remove. Protoxide of iron, though in a very low degree, and its isomeric compounds, are solvents of titanium; but the quantity required for this purpose is so large that we cannot think of making use of them in the blast furnace. On this principle the Catalan forge is conducted; the titanium of the ore is carried off by the subsilicates of that process. At the blast furnace, all our endeavors are directed to the extraction of every particle of iron from the ore. We thus act in a manner precisely the reverse of that in which we ought to act in this case. Instead of being indifferent concerning the loss of a small quantity of ore, the heat is increased, and most of the iron revived; while the titanium, thus deprived of all chance of leaving the furnace peaceably, remains with some of the cinder as a cold, pasty mass, which the hottest blast will not soften into a fluid slag.

If we wish to revive most, or all of the iron, in cases where titanium is the enemy against which we have to contend, our most successful plan of operation is to increase the foreign matter, and to form a large quantity

of a more or less fusible cinder, according to the quality of metal to be made. In this case, as in other cases, it is not advisable to employ pure silex, or pure clay or lime; but to select ferruginous clay, ferruginous slate, or lime containing iron. Pure lime and pure clay are injurious in every instance. Titanium is subject to the general law of the solubility of the oxides of metals in silicates; and the more fusible such silicates are, or the lower the temperature at which they melt, the greater is their dissolving power. Hence, where the amount of titanium is large, the amount of cinder should be uncommonly large, to produce gray iron; but if we are indifferent about the loss of a little ore, and smelt white forge metal at a low temperature, the fluxing of the furnace requires but little foreign matter. Ores containing titanium may be considered very favorable for the manufacture of steel metal; in many respects, they are preferable to the spathic ores; for, with very little attention, they will produce white iron with a large amount of carbon, the very material from which German steel is manufactured. For this purpose, a high stack, and a low hearth, or none at all, like the Styrian furnaces, are required: as well as the addition of a flux which shall carry off the titanium. A sandstone hearth would not answer so well as a hearth of granite and gneiss.

Cinders No. 4 and No. 5 possess but little interest; but Nos. 6 and 7 are taken from a furnace of which we have personal knowledge. This furnace is known to produce a first rate article, from which German steel for the Solingen market is manufactured. No. 6 was taken while the furnace labored under too heavy a burden; the metal produced was white, serviceable for the manufacture of bar iron. No. 7 was derived from the furnace when in good order, and while smelting gray iron, a kind of foundry metal. But for this purpose the furnace is seldom employed; because the region in which it is situated abounds in rich spathic ore, and supplies no ore of inferior quality. This rich spathic ore is scarcely at all adapted to produce soft gray iron. From the same furnace we have a third specimen of cinder

from a different source; this cinder was made when the furnace was smelting steel metal, that is, a white, crystallized metal, containing a great deal of carbon. As the manufacture of steel metal is yet to be carried on, in this country, to a very great extent, as soon as our ores shall be better understood, we shall make some remarks which may be useful to those who design to engage in its manufacture. We shall call the following specimen of cinder, No. 12:—

Silex	.	.	.	.	.	48.39
Lime	.	.	.	.	.	"
Magnesia	.	.	.	.	.	10.22
Alumini	.	.	.	.	.	6.66
Protoxide of iron	.	.	.	.	.	.06
" " manganese	.	.	.	.	.	33.96

The ore employed in cinders Nos. 6, 7, and 12 was of the same composition. Nothing but its burden was changed. In No. 6 it was heaviest; in No. 7 lightest. It will be observed that there is a considerable increase of silex from No. 6 to Nos. 12 and 7. No. 7 contains the largest amount of silex, but scarcely any iron. The iron contained in No. 6 is replaced by magnesia, alumini, and manganese. Scientific investigation shows us that the cinder from gray iron contains fifty per cent. more oxygen in its silex, in proportion to the oxygen of the alkali, than the cinder from white iron, No. 6, contains; the latter is almost a single silicate, in which the oxygen in the acid is equal to the oxygen in the alkali.

The characteristic feature of cinder No. 12 is that it contains no lime. This is an important circumstance. The lime is replaced by manganese; but we cannot expect, in every instance, to find manganese in quantities sufficiently large to flux the cinder. This remark applies especially to the magnetic ores of this country. Therefore, if we wait until we find an ore which can be fluxed by the manganese it contains, before we succeed in manufacturing steel, we shall be under the necessity of waiting a long time. An addition of black manganese will be highly serviceable; but this can be only partially applied; partly on account of its expense, and partly

because of the limited quantity in which it is found. Neither lime, magnesia, nor any of the alkaline earths, are of any use. Protoxide of iron is inefficient, because, in spite of all our efforts, it will be dissolved by the temperature of the furnace, and the amount of carbon present. The only resource which remains is the alkalis proper, that is, potash or soda. Soda is preferable to potash.

Lime, in this instance, does not answer the purpose of a flux, for the following reasons: Metal adapted for the manufacture of German steel should contain a large amount of carbon, and be as free as possible from foreign matter; these are objects accomplished with great difficulty in the blast furnace. We are enabled to combine a large amount of carbon with iron in the blast furnace; as in the case of gray anthracite iron, or some charcoal iron. But this object is always effected by means of a strong, silicious cinder; and such iron contains a large amount of silex. But this iron, though an excellent forge metal, is not adapted for the manufacture of steel.

The combination of the revived metal with carbon may be effected with comparative facility, as we have before demonstrated. But in the present case, we need a metal free from foreign matter; therefore it is requisite that we employ an ore as free as possible from foreign matter. We have an abundance of such ores in this country from Maine to Alabama, and from Iowa to Texas; but the usual method of conducting blast furnace operations will not enable us to produce the required metal. Silex and clay, if they are present in the ore, do no harm to the metal; but lime is injurious. Lime facilitates the reviving of iron in a higher degree than any other alkali. While it protects the bright surface of the metal, it will prevent, and sometimes even dissolve, the combination of iron and carbon. For these reasons, lime is inapplicable to our purpose. Still another reason is, that the affinity of lime for silex is not sufficiently strong to prevent the combination of silex and iron; and in the presence of a surplus of carbon,

silica will be reduced to silicon, and, combining with the iron, will make it brittle, and useless for the manufacture of steel.

The application of soda or potash in furnace operations, as a means of fluxing, has been recommended by various writers; but we are not aware that a successful experiment has ever been made. While the application of these fluxes will improve the metal for the forge, it will impair its malleability as a foundry metal.

The hearth and in-wall of a furnace suitable for the manufacture of steel require a thoroughly different construction from those of ordinary furnaces. The material employed at common furnaces cannot resist the action of strong alkalies; but of the material of which a hearth should be constructed, we shall speak hereafter. A different internal form from that of common furnaces is required. The interior should be high; there should be no hearth, or a very low one. The blast should not be too strong, but in abundance. Very rich ores are desirable, in case artificial flux is to be employed, for expenses will augment in proportion to the amount of foreign matter contained in the ore. It is worthy of remark, that steel metal can be manufactured, so far as charcoal is concerned, at a very small cost; for, in Styria, where a large number of furnaces produce this metal, less fuel is consumed than in any other blast furnaces in the world.

The analyses of cinders Nos. 6, 7, and 12 show conclusively that cinders from the same furnace, from the same ore, and produced, with the exception of burden, under the same conditions, differ greatly in composition. Therefore we should be cautious in drawing conclusions from analyses of cinder, and avoid hasty imitations. We do not always know to what kind of work the cinder belongs. The theory of the artificial composition of cinder, which has of late been so highly developed, may, while it is useful to the utilitarian, seriously mislead the speculator, who, in his eagerness to secure profitable results, fails to examine whether his conclusions are drawn from sound or insufficient premises. The rules with which science has furnished us in relation to the

rudiments of the business have, thus far, been applied only to a very limited degree; therefore we cannot expect that improvements, based upon conditions thus incompletely fulfilled, will be altogether successful. Speculative minds are too little disposed to notice slight imperfections; but these imperfections constitute the greatest obstacle to the progress of the business. Were they properly estimated, and due pains taken to correct them, the United States would be enabled, in a few years, to compete against the world in the manufacture of iron.

We conclude that cinder No. 10, on account of the large amount of lime it contains, produced red-short iron and white metal. No. 9 is decidedly of better quality; and close investigation will show that this cinder produced gray metal. To enter into details upon this subject would probably be less acceptable to the reader than to present the subject in as brief and significant a manner as possible. We infer that No. 10 produced white iron, because the amount of oxygen in the alkali is greater than that in the silex; whence it follows that the cinder is a basic or subsilicate. To make gray metal, at least a single silicate, that is, the presence of an equal amount of oxygen in the alkali and acid, is required. The process will be more effectual if the amount of oxygen in the silex is greater than that in the alkali. This is the case with respect to No. 9; and, in spite of the large amount of protoxide of iron present, the cinder is the result of a good quality of metal. If not excessively gray, it is at least good foundry metal, made by cold blast. No. 10 is a peculiar cinder, and is from the same furnace as No. 9. The furnace is said to have been in bad order; but this cannot be true, because the amount of sulphur in this cinder is 1.4 per cent. Nearly three tons of cinder, at a coke furnace, are produced per one ton of metal; therefore, should a good cinder have been made, the iron of No. 9 ought to contain three times 1.4 per cent. of sulphur. But this amount would render the iron entirely useless, even though the largest proportion of sulphur present was

expelled. Be this as it may, the coal or the ore of the furnace at the Dowlais Works, in South Wales, contained a large amount of sulphur, which is visible in No. 10. We allude to this cinder especially, because it was produced under conditions which resemble very closely those which exist at the Great Western Iron Works, in Pennsylvania.

The presence of sulphur in the furnace occasions great annoyance. In the case before us, the furnace required a large charge of limestone to produce, even at a high temperature, a surplus of lime; for this is the best means of carrying off a certain amount of sulphur. A high temperature will produce a white cinder, streaked with various shades. This cinder contains, besides a silicate of lime, a sulphuret of lime, and is characterized by soon losing its lustre on being exposed to the atmosphere. If, under such circumstances, the temperature of the furnace falls below a given point, the cinder changes rapidly into a pitch black, heavy mass, containing a large amount of sulphuret of iron. The same circumstance happens where too small a quantity of limestone is used. In this case, the sulphur, having no free alkali with which to combine, follows the iron into the pig bed, where its presence is indicated by the odor of sulphurous acid. If the furnace is cooled below the temperature at which gray iron is usually made, the cinder, by absorbing sulphuret of iron is soon blackened. In such cases, the smelting of gray metal is accompanied with difficulties which absorb more attention than can well be spared. In addition to the difficulty of continuing a furnace on gray iron, the metal produced is of inferior quality, and unsuitable for the market. To get rid of the sulphur is indispensable, for, whether we bring the pig iron to the forge or to the foundry, it is, in all cases, exceedingly troublesome.

There is no resource left but an excess of limestone. This will, of course, produce white metal, and, if hot blast is employed, of very inferior quality. In this case, it is necessary to work the furnace with light burden, to prevent the formation of black cinder, which will absorb

too much iron. The revived iron, or iron ore, in the upper part of the furnace, will be saturated with carbon; and at the high temperature of the hearth, the silix, and even the lime, will be reduced to their corresponding metals. These metals will combine with the iron; and having, where hot blast is employed, little chance of being oxidized, they will of course follow the iron to the bottom, and be troublesome both in the forge and in the foundry. Metal, thus produced, is so brittle and hard as to be unfit for foundry use.

We have thus presented an instance in which white iron, smelted by a high temperature, contains little or no carbon. In charcoal furnaces, on the contrary, the metal contains a large amount of carbon; but this applies only to those cases in which no limestone, or limestone in very small quantity, is used. In this, as in every case, the disappearance of carbon results from the large quantity of lime in the furnace. The result is the same, under similar circumstances, in charcoal furnaces. The weakness of the metal is to be attributed principally to an admixture of silicon, and perhaps of calcium—both very bad admixtures—with the use of hot blast. In this case, the cold blast will produce better metal than hot blast, because of the oxidization of silix by the former. By the latter, the oxygen is not so quickly absorbed; the iron which sinks is more exposed to oxidation; and of course calcium, silicon, and carbon will be sooner oxidized than iron. But of this matter we shall speak hereafter.

As we have seen, cinder No. 10, compared with No. 9, contains very little iron. This cinder may be considered the regular mixture of ore and flux for the location whence it was derived; because, if it contained less limestone, the metal, in addition to being very hot-short, would be produced in very small quantity. A surplus of limestone would produce a better yield, more easy work, and metal of good quality, however white it might be. The application of cold blast in smelting is, so far as the quality of iron is concerned, undoubtedly preferable to that of hot blast, because of the large quantity of lime

which is exposed to its action. Where the blast is cold, the limestone will be chilled; and the cinder and iron, in their passage through them, will also become chilled. Where hot blast is employed, there is a more uniform heat in the hearth, and no obstacle prevents the passage of the cinder; because even the unmelted parts are sufficiently warm to facilitate the process of smelting, and the discharge of the fused mass.

From what we have stated, we deduce the following conclusion: that the best method of using sulphurous materials is to smelt them by an excess of alkalies. The resulting metal may be gray or white. This is both theoretically and practically true. We may add, that the smelting of sulphurous minerals should, where practicable, be avoided. But where we cannot avoid using them, we should employ the hot blast, and work with as low a temperature as possible, with the view of expelling silicon.]

CHAPTER VI.

PRACTICE OF CHARGES, MIXING OF ORES, CINDERS.

THE term charge is used at the blast furnace to indicate the proportions and amount of coal, ore, and fluxes, in the aggregate, put in at the tunnel head of the furnace, and from which the iron is "reduced," or "revived" as it was formerly styled.

Iron-masters are turning their attention more and more to the importance of the proper mixing of their ores. We wish to speak of ores in their component parts and the customary mixing proportions, together with the resulting irons and cinders both cold and hot, for although, scientifically, we hear much of the color and composition of *cold* slags, any iron-master knows that *hot* slags will, to a practised superintendent, indicate the state of the furnace, and, indeed, almost the

very grade of iron in the furnace hearth just under that hot slag.

We are well aware that the Charge Book is the innermost history of intelligent action on the part of an iron furnace company, and that, as in steel works, not every manager is willing to have his "proportions" or his Charge Book overhauled. But we are also aware, as many others are, that two managers may work at two furnaces with exactly the same charges and the same ores, and yet not always produce exactly the same iron. Much is dependent upon the furnace, its hot blast, pressure of blast, and upon the manner of preparing and introducing these charges, the height of tunnel head, etc.

There is no very great and mysterious secret in charges, to the practically scientific man who thoroughly knows the composition of his ores, limestone, and coal.

It is evident, then, that the essential prerequisite in the determination of a proper charge, is a perfect knowledge of the nature and composition of the ore, limestone, or other flux and the coal, coke, or other fuel used in the charge: that is, a knowledge of elements and of their proportions. This is the first step. The second is to ascertain the effect of any element in the ore upon the iron about to be made from the ore, or its effect upon the cinder whose fluidity and nature would be satisfactory in the absence of that element. For instance, a good cinder may be, as we have quoted from Percy (page 165), silix 38, alumina 15, lime 47 in one hundred parts, when the gangue consists purely of these ingredients, or elements, and there is nothing else present in that ore but oxide of iron. It is not necessary that these proportions be strictly observed: a slight variation of one or two parts, as we have repeatedly found in the laboratory, is not followed by any perceptible variation in result, so that we may say that a good type flux, or charge, is 5 of silix, 2 of alumina, and 7 of lime. Were these the only elements, and were they in these proportions exactly, in every ore, then all that would be needed would be coal sufficient to raise the ore to the necessary temperature and the gangue, or the silicious, aluminous, and calcareous

elements would unite, become liquid, rise to the surface, and the iron being heavier would subside to the hearth, and the work of reduction would be complete. But even if this were the case, there is, sometimes, a quality of iron required which cannot be obtained by this course, or by Dr. Percy's type, which is, emphatically, a special British coke type, nor indeed by any one type however perfect in itself. For foundry purposes, a gray, and thoroughly liquid iron is called for. The iron is not carburized if the method of charging be strictly carried out as above stated. Therefore the carburizing desired must be effected by means of the coal, and one step in departure from the above method is such a disposal of the coal that more carbon may be brought in contact with the iron than is necessary for the mere effect of heating; that superabundance of carbon will therefore be left free to unite with the iron under the condition of heat, to which we have already alluded in a previous chapter in Part I. This, therefore, is the simple statement of the practical first principle upon which we proceed in the proportioning of the elements of all charges in the blast furnace.

We shall introduce the practice by a series of examples of charges as proportioned in successful practice abroad, and afterward by a series of the same at home, and close this chapter by some practical remarks as deduced from the whole European and American practice.

Let it be understood that while there may be a type cinder, there will be modifications, and these are to be noticed as we proceed, for they are suggestive of the presence of elements which give reasons for an alteration of the typical proportions we have given.

The Cleveland, England, main bed of iron stone will, on the average, lose 25 per cent. by calcination. The raw stone thrown roughly into a heap will weigh about 1 cwt. per cubic foot when not too wet. The calcined stone will weigh $\frac{3}{4}$ cwt. per cubic foot when drawn from a kiln.*

* Engineering, Jan. 18, 1867.

That Cleveland ore, or iron stone, yielding iron celebrated in England, has the following composition:—

Per oxide iron	47.50
Protox. manganese	0.58
Alumina	9.80
Lime	4.28
Magnesia	4.32
Silica	10.30
Sulphur	0.04
Phosphoric acid	1.12
Loss by calcination	22.43
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	100.37
Metallic iron	33.25

The limestone used in Cleveland is principally the carboniferous limestone, from Weardale, in Durham, of the following composition, and it is preferred to the magnesia limestone found nearer at hand:—

	Per cent.
Carbonate of lime	93.72
Carbonate of magnesia	3.63
Peroxide of iron	0.23
Alumina	0.83
Silicious matter	1.76
Moisture	0.09
	<hr/>
	100.26

The analysis is of clean samples of limestone free from any soil. Another sample slightly varies as follows:—

Carbonate lime	95.38
“ magnesia	2.46
Alumina	0.38
Protoxide	0.29
Silicious matter	1.83
Moisture	0.10
	<hr/>
	100.44

Calcined limestone is used in only a few cases in Cleveland, with a certain advantage, but which advan-

tage is smaller in the large furnaces than in the smaller ones.

The coke is from South Durham, analysis as follows:—

Carbon	91.42
Volatile hydrocarbons	0.64
Sulphur	1.00
Ash	6.66
Moisture	0.28
	<hr/>
	100.00

The South Durham coke will weigh about 36 lbs. per cubic foot. One ton of this coke, when made in the old round ovens, represent as nearly as possible 2 tons of coal, but in flued coke ovens of improved construction, where all possible advantage is taken in consuming the gas and smoke from this very bituminous coal, as much as 65 per cent. of superior coke is got from the same coal.

The quantity of coke per ton of foundry iron is about 25 cwt. This, with the exception of the coal slack used in calcining the ore (which is 6 cwt. per ton of iron made) is all used at the furnaces. The No. 1 foundry pig iron, from the Acklam furnaces, gives

Iron	91.37
Graphitic carbon	3.40
Combined "	0.08
Manganese	0.64
Silicon	2.73
Sulphur	0.07
Phosphorus	1.33
Vanadium	0.38

There are traces of some other metals, titanium, &c., in this iron, but it is an excellent foundry iron, and competes with Scotch pig in many continental markets as well as in England.

It is said that there is no standard of charge adopted in Cleveland. It varies from 1 ton to 2 tons of coke, with ironstone and limestone in proportion. But Dr. Percy, on the authority of one of the proprietors, gives

the following general proportions of the above ore, stone, and cokes for foundry iron:—

	cwts.	qrs.	cwts.	qrs.
Cleveland ore	8	0	to	8 1
Limestone	2	2	to	2 3
Coke	6	0		

The following is an analysis of Cleveland blast-furnace slag. Color, light gray; fracture, stony; iron, gray foundry:—

	per cent.
Silica	32.81
Alumina	23.40
Protoxide of iron	0.33=0.26 metallic iron
Protoxide of manganese	0.18
Lime	34.90
Magnesia	7.46
Phosphoric acid	slight trace
Sulphur	1.78
	<hr/>
	100.86

Another analysis of slag from the same foundry iron, gave a little variation as follows:—

Silica	32.94
Alumina	23.32
Protoxide of iron	0.46
“ manganese	0.09
Lime	34.94
Magnesia	7.33
Phosphoric acid	slight trace
Sulphur	1.88
	<hr/>
	100.96

At Barrow-in-Furness, the consumption of coke per ton of iron averages 20 cwt. The ore is used in the raw state, giving an average yield of 57 per cent. of iron, requiring nearly 20 per cent. of its weight of limestone as flux. The charge is 34 cwt. of ore, $6\frac{1}{2}$ cwt. limestone, and from 19 to 21 cwt. coke. The method of charging is as follows: There are six openings at the furnace top, made in the usual way, and in filling, five of these openings are charged in succession, and the sixth is passed

over and then the filling commences as before, but beginning at the next to the one previously begun with. This method leaves a spiral of loose material all around the outside of the furnace-charges, and is said to prevent sticking and scaffolding. The bosh is 16 ft. 6 in. and the height 56 ft. The furnaces are tapped every 6 hours, giving 20 tons each cast. Each furnace has six tuyeres and temperature of the blast is 600° to 650° Fah. Pressure 3 lbs. and $3\frac{1}{2}$ lbs. per in.*

The cinders produced by the manufacture of (red) hematite pig iron, for the Bessemer process, contain an unusual amount of lime and other basic matter. The falling to pieces by exposure to air is the proof of the superabundance of the lime. At the Kirkless Hall Iron Works, at Wigan, the following slag is made—

Silica	31.46
Lime	52.
Alumina	8.5
Magnesia	1.38
Protoxide of iron	0.79
“ manganese	2.38
Sulphide of calcium	2.96

The super amount of lime has the tendency to extract the sulphur, as we shall see more fully hereafter, and hence the propriety of charging with so much lime where sulphur exists. The appearance of the slag is that of wedgwood ware. Mixed with sand and water it forms an excellent mortar, but partakes somewhat of the nature of hydraulic cement. According to this account, therefore, the slag must contain more lime than is usual, and the slag which was considered that of a good iron is not in accordance with the type slag of Dr. Percy, as we have given before. The proportions of 38, 15, 47, for the silex, alumina, and lime should have required for a slag like the above, containing 31.46 of silex, the following proportions, namely, of alumina 12.4 and of lime 38.9, since the proportions 38, 15, 47 of the type adopted by Dr. Percy should render this slag 31.46,

* Engineering, 1868.

12.4, 38.9, instead of 31.46, 8.5, 52. We see therefore the conditions altering the above proportions, and would direct attention to it, for the above cinder is, of its kind and under its circumstances, a type, or model cinder.

Nevertheless, as Bodemann has shown, the following combination is of the greatest fusibility—

56 silica,	containing	24.9 oxygen.
14 alumina,	"	8.9 "
30 lime,	"	8.6 "

Wherein we see the contrast to the above type by Dr. Percy, and yet we must not be led astray by this fact, for a fusible combination may not be either a practicable one, nor available, for the end desired, namely, good iron. Hence it is not a practical question, How fusible can I make my combination of members in the charge, but rather, What are the combinations in that slag which has performed its duty—done its work well—what is to be learned from the combination found in *that* slag? Although in the above cinder we have a departure from all theoretic types, we have a good type and a very much heightened infusibility of slag; yet the object has been better reached than by either of the above proportions found in the type. Herein the practical and scientific good sense of the manager is to show itself in making types to suit his special ends.

With a view to the nature of charges so far as may be seen from a large number and range of slags, we present the following from analyses by Klasek, Karsten, Berthier, Bodemann, Rammelsburg, Dronat, Hess, and other careful analysts, from Prof. Kerl's Metallurgy, as adapted by Dr. Crookes. A careful review and examination of these analyses, in accounting for the corresponding physical nature and appearance of the slag, will impart very valuable suggestions.

I. Slags from Charcoal Blast Furnaces.

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO ³	70.23	70.12	60.0	60.44	53.0	52.8	59.42	53.79
Al ² O ³	6.37	6.25	7.4	3.27	1.0	3.4	14.94	13.04
CaO.....	20.41	19.71	20.6	19.73	15.0	5.6	19.79	25.67
MgO.....	...	.70	7.2	7.01	8.0	9.0	.11	0.57
FeO.....	0.15	1.45	3.0	4.89	10.0	1.4	6.03	2.44
MnO.....	2.70	1.40	3.6	4.28	10.0	26.2	trace	2.20
S.....	...	...	...	0.36	...	...	...	...

	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
SiO ³	49.57	49.0	46.371	49.70	31.1	37.8	27.48	29.0
Al ² O ³	9.00	21.8	4.301	9.10	8.9	2.1	25.78	6.3
CaO.....	...	24.0	38.640	16.20	14.1	...	25.47	23.4
MgO.....	15.15	trace	7.400	10.30	34.2	8.6	.41	15.7
FeO.....	0.14	2.1	0.950	3.70	1.0	21.5	.91	23.7
MnO.....	25.84	0.6	1.860	10.80	4.4	29.2	2.59	1.4
KO.....	...	0.7	.089	...	...	...	...	...
NaO.....	...	0.7	.138	...	...	...	...	...
CuO.....	...	...	trace	...	...	...	...	...
PO ⁵.....	...	...	trace	2.60	...	...	...	9.66
S.....	0.30	trace	0.030	0.40	9.0	...	...	...
Loss.....			...	...	...	...	...	...
TiO ².....	...	...	...	...	...	...	...	6.70

Physical Appearances of the above Slags.

- I. A bluish-white enamel-like slag; gray pig; spathic ore.
- II. Bluish-white, vitreous, pellucid at the edges; bog iron ore.
- III. Vitreous, bluish-gray, striped; red and brown hematite.
- IV. Pellucid, bluish or greenish-gray, enamel-like; for cannon.
- V. Blistered, black slag from irregular process in Savoy; spathic ore.
- VI. Well fused slag, partly stony, partly vitreous; spiegeleisen; spathic ore.
- VII. Black slag, irregular process.
- VIII. Vitreous, green slag; mottled iron.
- IX. From Hammhütte, a regular process, peculiar; [spiegeleisen? spathic ore?]
- X. Darkish, green and violet blue, vitreous, difficult to fuse, graphitic on surface; gray pig.
- XI. Slag from Dannemora mixture, Sweden; Bessemer pig.
- XII. Slag from phosphatic ores, Dalekarlien.
- XIII. Yellow, blistered slag, difficult to fuse; Taberg mag. ore.
- XIV. Slag from irregular process, iron with little carbon; white pig; spathic and brown.
- XV. Pumice-like slag.
- XVI. Black blistered slag, Styria, irregular process; [spathic?]

The following are slags, with their characteristic physical conditions, from

II. *Coke Blast Furnaces.*

	I.	II.	III.	IV.	V.	VI.	VII.	VIII.
SiO ³	50.00	46.60	46.46	39.95	40.20	41.64	42.94	45.64
Al ² O ³	23.00	15.80	18.80	17.41	16.45	13.20	16.29	10.84
CaO.....	27.00	10.80	25.60	29.64	30.	35.91	31.10	35.01
MgO.....	...	2.28	3.50	6.47	7.29	4.21	4.16	3.16
FeO.....	...	7.56	...	.24	.57	.11	.34	.71
MnO.....	...	3.40	2.80	.91	.84	.74	.51	trace
KO.....	...	2.40	...	1.46	1.30	1.70	1.87	.82
S.....	...	...	0.70	...	...	...	...	...
CaS.....	...	11.70	...	3.60	2.71	2.19	2.16	3.30
PO ⁵.....	...	...	...	trace	trace	trace	trace	trace

	IX.	X.	XI.	XII.	XIII.	XIV.	XV.	XVI.
SiO ³	41.11	41.11	37.84	38.80	34.25	34.90	28.80	20.02
Al ² O ³	9.46	13.45	13.20	15.20	16.70	5.80	12.30	30.00
CaO.....	37.90	29.82	20.68	37.00	38.81	50.63	56.30	39.06
MgO.....	2.11	4.75	2.93	3.20	1.53	.93	.57	4.38
FeO.....	.49	6.44	20.83	4.40	.84	6.52	.70	3.86
MnO.....	1.61	.66	.80	...	1.51	1.04	...	0.21
KO.....	.71	1.84	1.08	...	1.21	...	...	trace
S.....	...	...	...	.80	...	.08	1.15	...
CaS.....	.41	1.34	.87	...	5.48	...	0.50	1.43
PO ⁵	trace	.15	1.77	...	...	...	...	trace

I. Medium composition of slags Eng. and Belgium. Foundry iron, hot blast.

II. Forge pig.

III. Normal slag at Gleiwitz.

IV.—XI. From Staffordshire, analyzed in an investigation, and of effect of hot blast upon phosphorus in pig.

IV. and V. Gray iron and cold blast.

VI. and VII. Gray iron and hot blast.

VIII. Gray iron and hot blast from oölitic ore.

IX. The same from puddling slags.

X. Slag thin, liquid, like black bottle glass; white pig iron produced.

XI. Same from oölitic ore and irregular process.

XII. Dirty brown slag, glistening on its fracture; from spiegeleisen.

XIII. Slag from Westphalia, from gray iron from Black Band; blast 300° C. 570° (Fah.).

XIV. Slag black when in thick pieces, but pellucid and light green at edges.

XV. Slag obtained at the contemporaneous production of zinc and pig iron. It disintegrates forming dust.

XVI. From Westphalia [normal iron].

III. *Slag from Anthracite Blast Furnace.*

The following is from iron works Gartsherrie and Govan, Scotland—

SiO ³	.	.	.	.	.	.	.	35.34
Al ² O ³	.	.	.	.	.	.	.	20.47
Ca O	.	.	.	.	.	.	.	38.72
Ca S	.	.	.	.	.	.	.	1.35
Mn S	.	.	.	.	.	.	.	5.39

The following is from a Buffalo, N. Y., Anthracite Furnace, working well on foundry iron and Lake Superior red hematite—

FeO	.	.	.	.	.	.	.	0.55
SiO ³	.	.	.	.	.	.	.	39.35
CaO	.	.	.	.	.	.	.	37.63
MgO	.	.	.	.	.	.	.	3.65
Al ² O ³	.	.	.	.	.	.	.	13.86
MnO	.	.	.	.	.	.	.	2.40
S	.	.	.	.	.	.	.	2.42
P	.	.	.	.	.	.	.	trace

99.37

E. S. MOFFAT (1868).

The slags from anthracite do not differ essentially from those making the same iron with the same materials in the coke furnaces, excepting, that, as in above instances, a larger quantity of sulphur in the coke may demand more lime upon principles and a practice we shall present more fully hereafter.

Multiplying fluxing materials in the charge is beneficial just so far as it brings together more thoroughly, and mixes more intimately, materials having fluxing affinities. The whole theory of good results from mixing ores depends upon this principle. Silicious ores flux well when mixed with ores containing alumina, and then the dead flux would be limestone. But this fact must again be modified by the manner in which the silex occurs in the ore, whether as mechanically mixed as an incrustation or otherwise. If united chemically, the flux ore or dead

flux will unite more satisfactorily. Again, a magnetic or massive ore, very rich and pure, will be treated with greatly more success and ease, if the fluxes, together with the ore, are thoroughly and uniformly reduced in size, and when leaner ores form the complement of flux ingredient demanded by the types of a good slag as we have given them. Thus, as we shall see, in the anthracite blast furnace at Port Henry and elsewhere on Lake Champlain, where no ores but the Champlain magnetites are used in the charges—the rich Cheever magnetic ore is mixed with a leaner ore, aluminous in its nature, broken up and mixed, at the tunnel head, with the pure white sparry carbonate of lime. The leaner ore (generally the Barton ore) has a large silicate of alumina-gangue, and the slags which we have examined, and which have been made for years, contain the ingredients SiO^1 , AlO^2 , CaO , with FeO and in some cases TiO^2 with a small per cent., lately, of CaS . Reduplications of magnetic ores, for instance, ores containing slight traces of lime-phosphates, with ores containing siliceous mechanically mixed, both of which are found in Morris County, N. J., and the neighboring counties, together with aluminous or hornblendic ores all mixed in the charge with the brown hematites of the Lehigh Mountains and the hematite beds stretching along west of the Delaware, at Easton, result in great economy and satisfaction both in fusibility of slag and quality of iron. Especially is the above practice excellent when sulphur is in some of those magnetic ores mixed with the phosphatic ores, although this is only one of the benefits derived.

On Lake Ontario, we have been told by Mr. French, who, we understand, has had more than twenty years' experience in working the fossil ores of Oneida County, (see Fossil Ores) that, in some veins, the lime and siliceous contained in the ore was quite sufficiently well proportioned to enable him to flux it in itself with charcoal and without any lime, but that in some veins he found a necessity of using a ferruginous clay in proportions of 1200 lbs. clay to every 6 tons of iron made. He used

150 bushels of medium hard charcoal to the ton of iron made. The clay was introduced in small cubical charges from boxes. This practice produced the finest foundry pig. Yet the ordinary veins of fossil ore required one half Lake Superior red hematite (silicious) to one half fossil (with lime); the siliceous, lime, and the alumina of the clay, in that case, rendering the most perfect foundry iron and most satisfactory results.

We see therefore the principle upon which the judgment of the manager must be formed in determining his charges. We shall give some actual instances of procedure where various treatments have been followed by satisfactory results.

A fine foundry iron is made in Alleghany, Pa., in a coke furnace (Benjamin Crowther, manager) from the following ores and limestone. The charges contain a large amount of limestone for the purpose above stated, namely, elimination of sulphur. The Charge: Coke, 450 lbs.; Jackson ore, $247\frac{1}{2}$ lbs.; Sand-Pit ore, 85; manganese ore, 25; mill cinders, $42\frac{1}{2}$; in all 400 lbs. Limestone, 200 lbs. Slag, opaque, light bluish-gray, shows the lime very decidedly as it slacks in the road and gives off slight sulphurous odor, is very uniform in color.

In this charge the Jackson ore is a close red hematite — with an almost magnetic lustre, high specific gravity, 46 per cent. iron, tending to be red-short ore. Sand-Pit is a magnetic ore tolerably pure and somewhat granular, 50 per cent. iron. The manganese ore is from Lake Superior, with 50 per cent. iron (about 10 to 12 per cent. per ox. Mn.), only 10 per cent. is used, generally; the charge makes a strong and dark foundry iron. The limestone is a fossiliferous limestone very largely carbonate of lime and some 3 to 4 per cent. phosphate of lime, inclining to make a cold-short iron, but can be counteracted by the judicious intermixture of this Jackson ore. The furnace is blown with seven tuyeres, nozzles $2\frac{1}{2}$ inches in diameter. 3 lbs. pressure; heat of blast 600° .

A good mill iron (forge, strong white iron) is made from

$\frac{1}{2}$	Jackson ore	}	mixed ores, called ore.
$\frac{1}{4}$	Magnetic		
$\frac{1}{8}$	Mill cinders		
$\frac{1}{8}$	Manganese ore		

Burden:—Coke, 450 lbs. ; ore, 500 lbs. ; limestone, 200. Here we see effects of increasing ore.

Another white iron of excellent quality is made from the above mixture with 50 lbs. more ore.

The size of the furnaces above alluded to—

45	feet	high
6	"	hearth
13	"	bosh
5	"	tunnel head

Average weekly make, the year round, per furnace, is 150 tons gross.

The following gives the practical character of the charges and mixing of the ores, fuel and limestone at Scranton, Pa.; fuel, anthracite—hot blast 400° to 500°—pressure 6 lbs., varying. The iron is used for the rolling mill at the same place. The relation between charges and results is easily seen in this table. The red hematite is the so-called fish-egg (fossil) ore from Oneida County, N. Y. [See Commercial Ores for its geological position]. The limestone contains a large per cent. of alumina, and in some masses may truly be said to be a slaty limestone. These furnaces are supposed to yield as great a quantity as any of their size in the United States, and are managed with great skill and success, as to both quantity and quality of iron.

LACKAWANNA IRON AND COAL COMPANY, SCRANTON, PA.

Result of Blast Furnaces for the weeks ending Saturday, February 15, 1862, and March 9, 1867.

Furnace.	No. of charges.	Kinds of ore used.				Material consumed.			Products of Furnaces.		Per centage yield.
		1. Oneida.	2. Bran- nan.	3. Taylor.	4. Hema- tite.	Ore.	Coal.	Limestone.	No. 3, pig.	Total.	
		lbs.	lbs.	lbs.	lbs.	tus. cwt. q. lbs.	tus. cwt. q. lbs.	tus. cwt. q. lbs.	tus. cwt. q. lbs.	tus. cwt. q. lbs.	
Feb. 15, 1862, No. 3,	44	450	450	900	...	652 17 0 16	7 0 16	235 9 1 14	375 10 1 22	375 10 1 22	57.51
	728	475	475	950	...						
March 9, 1867, No. 2,	537	337	...	1688	...	485 9 0 17	431 10 1 12	173 16 0 13	250 17 1 8	250 17 1 8	51.67
" " No. 3,	524	...	...	1750	350	491 5 0 0	421 1 1 20	187 2 3 12	252 12 0 6	252 12 0 6	52.42
" " No. 4,	595	363	...	1812	...	577 14 2 21	478 2 2 0	219 2 3 7	302 11 2 12	302 11 2 12	52.37
Total						1554 8 3 12	1330 14 1 4	580 1 3 4	806 0 3 26	806 0 3 26	

1. Red hematite from Oneida Co., N. Y. 2 and 3. Magnetic from New Jersey. 4. Brown hematite from Lehigh Co., Pa.

Another proportion in charging, with the corresponding results, may be found in the following, from Grubb's furnace, near Columbia, Pa.: Fuel, anthracite; limestone has some magnesia, a little alumina. Limestone is good. The Chestnut Hill ore is the usual brown hematite. "Codus" is a lean magnetic; for Cornwall see "Commercial Ores," "Magnetic Ores."

	Pounds.	Mixed Ore.
Coal	2000	} $\frac{1}{2}$ Chestnut Hill, $\frac{1}{4}$ Cornwall, $\frac{1}{4}$ Codrus.
Mixed ore	2800	

Limestone, 1260 lbs. or 45 per cent. of the ore.

For a ton of iron it takes, on an average, $1\frac{3}{4}$ tons coal, $1\frac{1}{4}$ tons ore, and about 1800 lbs. limestone (45 per cent. exactly would be 1712 lbs.). A very interesting salamander was thrown out from the hearth, some time ago, which was lying out upon the river bank when we succeeded in breaking off pieces containing a profusion of light straw-colored crystals of chrysolite (olivine) in trimetric crystals; it is a silicate of magnesia and iron, showing the previous existence of magnesia in the furnace fluxes used. Dr. E. Swift, of Easton, gave us a specimen obtained some years ago at Cooper's furnace, Phillipsburg, N. J., of the same nature exactly. The excessive magnesia from the limestone may suggest the reason why the furnace chilled.

At the Shawnee furnace, near the same town, the charge consists of 1000 lbs. coal (anthracite), 1100 to 1400 lbs. ore, 50 to 54 per cent. limestone of good quality; Cornwall (Pa.) ores, and others similar, are used with like results, or very little variation, in either quality or quantity as compared with the iron of the other furnace. The cinders are good, and show much lime, which prevents a degree of red-shortness from the use of the "coppery-sulphury Cornwall ore," which would have exhibited itself in the iron but for the judicious application of the limestone. The latter contained from 10 to 21 per cent. magnesia, a large per cent. of carb. lime, very small per cent. siliceous, and a trifling amount of alumina.

An extremely fine, uniform, strong, open foundry iron has been made at the Saucon Iron Company's Works, G. W. Whitaker, Superintendent, Hellertown, Northampton County, Pa., from the following charges: Fuel, anthracite; limestone, a bluish stone, lime 28.38; magnesia 18.93; iron perox. 1.59; CO^2 44.12; insol. matter 6.73. (Roepper.)

Charges: 2400 lbs. coal (anthracite); 2700 mixed ore ($\frac{3}{4}$ brown hematite), $\frac{1}{4}$ magnetic (massive, about 2 to $2\frac{1}{2}$ per cent. sulphide) Morris County, New Jersey; 1750 limestone. $\frac{2}{3}$ of the $\frac{1}{4}$ magnetic was "Byram" mine (magnetic ore, contains silex, alumina, with 1 to 1.75 sulphide), balance of magnetic from various points.

Average charge: 2 tons coal (2240 lbs. to ton), 2 tons 5 cwt. 1 quarter of ore, 1 ton 8 cwt. of limestone, to the ton of iron.

The hematites are from Saucon Valley.

On the above charges there were made, weekly, 203 tons, nearly all No. 1 foundry iron, of quality above stated.

We know of no No. 1 iron superior to that which, for some weeks, last spring and summer (1868), was made at this furnace. We have given a description of the furnace in a previous part of this work.

For selected samples finest foundry pig iron No. 1x at Crane Iron Works, Catasauqua, Pa., the following charges have been found to work well. Fuel: Anthracite, Lehigh basin; limestone, much the same as in preceding case.

Coal, 500.3; hematite, 400.2; magnetite, 100.2; limestone, 300.3.

The hematite was generally nodular and fragmentary, from the Upper Silurian, and described in "commercial ores" under brown hematite as from Ironton, Pa. The magnetite was a granular and massive variety from Morris County, New Jersey. The limestone of analysis as follows:—

Moisture.	.	.	.	.	.	.	1.68
CO ²	.	.	.	.	.	.	34.36
Silica	.	.	.	.	.	.	14.80
Magnesia	.	.	.	.	.	.	1.78
Lime	.	.	.	.	.	.	42.70
Iron sesquioxide	.	.	.	.	.	.	4.60
							<hr/>
							99.92

The iron in the above was from a vein running through the limestone specimen, but only in the specimen sent and in some adjoining parts of the limestone rock which itself was from the immediate vicinity of the ore in Lehigh County.

A very evident illustration of the results of increasing the ore of the charge, otherwise the same, may be seen in the following, also from the Crane Iron Works, which, under the same circumstances as above mentioned when No. 1 was made, produced hard No. 2 gray forge:—

Coal (112 to the cwt.)	.	.	.	cwt.	qrs.
Hematite	.	.	.	500	3
Magnetic	.	.	.	500	1
Limestone	.	.	.	100	2
	.	.	.	300	3

One mile farther up the Lehigh are the Thomas Iron Works, celebrated for their size and the convenience and perfection of all their appliances. A very excellent No. 1 x iron of high quality was run out from this furnace under the following charges:—

Coal 600 cwt.; hematite (same as last mentioned) 400.2 cwt.; magnetic, 100.2 cwt.; limestone, 400 cwt. and 14 lbs.

An exceedingly reputable forge iron for rolling mill purposes has been made at Bethlehem, Pa., with the use of mill cinder in the charges which were as follows: Fuel:—anthracite coal, 2000 lbs.; hematite, 915 lbs.; Magnetic ore, 610 lbs., (Cornwall ore): Mill cinder 305 lbs.; limestone, 1200 lbs.

In all the above furnaces it is customary to make the coal a constant quantity, unless for very particular and unusual reasons. The alteration of the charge, there-

fore, will consist only in the alterations of the ore and the limestone. The capacity of all the furnace appliances and powers as respects the coal, are first to be settled, after that the ore and limestone will be proportioned to the coal. The proportion of the limestone and ore will be in accordance with the nature, that is, the composition, equally of the ore and of the limestone. We have, in speaking of assaying of iron, given the theoretic proportions of silica, alumina, and lime. In practice we may begin by approximating that theoretic proportion, but it must be modified, for the presence of other ingredients, as we have intimated, in the fuel, as well as in the ore and limestone. It appears, from the aggregation of many charges of the last description that the approximation to the proper charge (of good anthracite = A, Ore = O, and Limestone = L) is in this arithmetical proportion, taking 150 parts as a whole, for foundry iron:—

60 A, 50 O, 40 L,

where the blast pressure is about 6 or 7 lbs., and temperature from 600 to 800° Fah.—twelve tuyeres, 2 to 2½ inch nozzles.

At the same time, within seven miles of the furnace using the last proportion we find another furnace with very little variation in the quality of limestone, or magnetic ore and with the same hematite and coal—in other words, with little variation in the nature of the materials, making an equally good foundry iron with this charge proportion,

60 A, 61 O, 43 L.

In this latter case the furnace management and conditions have materially to do with the result. We note also that the pressure is less, burden less, because of less height of stack—hot blast about 600°—nine tuyeres, 3 inch nozzles. Less iron per twenty-four hours, but very excellent. The contraction to a certain diameter of hearth at the zone of the tuyeres, an increased pressure of blast with increased heat, all things being otherwise equal, is almost uniformly followed by whiter iron, that is, less foundry iron. It must be particularly noted

that in the above typical proportion we have had regard to the hematites last described, when general composition is fairly represented by the following analysis:—

Peroxide iron	. . .	68.57=51 per cent. metal iron.
Alumina	. . .	10.45
Lime	. . .	.55
CO ²	. . .	.45
Magnesia	. . .	.07
Silex	. . .	6.44
Moisture	. . .	13.39
		<hr/>
		99.92

The above analysis, made in our laboratory, is of a fair average specimen of a clean piece of bomb ore from Williams Township, opposite Easton. Some ores, we have examined from the same general line of hematites running S. W., for twelve or fifteen miles, contain variable proportions of alumina; some specimens containing a lower and some a higher amount than the above; where the ores have not been properly washed they are charged with as high as from 15 to 20 per cent. of alumina, and cause even with silex, much trouble in the furnaces, for reasons now evident, namely, altered flux type.

The following analysis is of the dark brown compact nodular hematite used at the Thomas Works and Crane Works and is also used at the Balliot Furnace, some three miles from the Carbon Works, Parryville. The Balliot is the only charcoal furnace using it. This is an average specimen from Iron-ton, Pa. The beds have been described under Brown Hematites:—

Peroxide iron	. . . . .	59.38
Alumina	. . . . .	4.70
Silex	. . . . .	23.91
Water	. . . . .	10.23
Lime	. . . . .	1.05
Sulphur	. . . . .	0.35
Phosphoric acid.	. . . . .	0.59
		<hr/>
		100.21

(E. S. MOFFAT.)

The charcoal iron made from this ore is extremely pure and strong, and the tendencies are decidedly to a hard and tenacious chill, with nothing to prevent toughness, except, perhaps, the lack of some alumina. The furnace manager has acted upon this suggestion, and mixes this ore slightly with an aluminous ore, which, from experiment at Reading, Pa., on its tensile strength, adds tenacity to the cast iron. Renault* has proved that sulphides heated with carbon always part with a portion of sulphur; and Karsten,† that a certain proportion of phosphorus improves the iron in the qualities above stated. This cast iron made red hot, is, to a singular degree, malleable, and we have the proof in our possession.

A very few specimens of the above mentioned ores show traces of sulphur. Some, a quantity as high as 1.84 per cent. The best magnetic ores for mixing, in the above mentioned charges, assay as high as 63 per cent. iron, 7 per cent. silex, 1.50 per cent. alumina, with occasionally some magnesia, sulphur and lime, varying however, considerably in the iron and silex down to 57 per cent. iron, and up to 12 to 14 and even 20 per cent. silex. In the latter cases the limestone is increased and the magnetic ore in the mixed ore decreased, so that the proportions are about—

60 A, 58 O, 44 L.

The results are good foundry iron.

From the above we see that one object to be gained in mixing, is, to make one ore carry proper fluxes to another ore which requires such fluxes for fusion. And not only so, but that the flux, being in itself an ore, may, while bringing about a fusion, at the same time afford some metal with itself, and thus be an economical and not a "dead flux."

Besides the benefits derived from mixing ores, because of the complementary earthy materials, or gangue, the

* Ann. des Mines, 3 s., page 45.

† Handbuch, ed. 1841, p. 420.

mixing of ores, in a charge of iron ore, proceeds upon the supposition that certain injurious qualities in certain ores, may be corrected by other ores having qualities which shall neutralize those injurious qualities. For instance, sulphurous ores, producing red-short iron, may be modified by ores containing phosphorus, silicon, arsenic, or any other properties giving rise to cold-shortness.

Another advantage in the proper mixing of ores is found in the consequent strength which accrues to irons which have been formed under such proper and skilful commixtures. There can be no question that the mixing, in certain proportions, of certain magnetic ores with brown and red hematites of certain qualities produces irons of extraordinary toughness and of excellence in other respects. We have watched, for several months, some experiments of this kind in relation to certain ores taken from the range of magnetic ores upon the line of the Morris & Essex R. R., of New Jersey. They were mixed with the brown hematites above described, and the irons made therefrom have been thoroughly tested by us and in our presence, under such circumstances, at various times and in various places, as to set the matter at rest, that the mixing of one-eighth of a magnetic from one bed with one-eighth of magnetic from another bed with three-fourths brown hematite of certain quality will produce a pig iron of strength capable of bearing a pressure very largely increased upon that of a pig iron formed by the use of one-fourth of either of the same magnetic ores alone, or together, and without any mixture of hematite. It matters not which of the above selected magnetic ores are taken in the "one-fourth quantity." These three reasons, therefore, are given for mixing ores: 1. More economical fluxing. 2. Correction of either cold-shortness or red-shortness. 3. Greater excellence of the iron produced.

Some excellent irons, with coke as fuel, have been made by mixing the carboniferous, or coal measure, argillaceous ores with the red fossil ores (for reason No. 1). with some brown hematite for reason No. 2.

As we have stated under "Commercial Ores," there

is in the regions of the coal measures, an "out crop brown hematite." We have seen it in the anthracite basin as well as west of the Alleghany Mountains. This has been very successfully mixed with the argillaceous and carbonate iron ore upon the reason No. 2. Also, the hard limestone coal measure iron ore with Lake Superior red hematite upon the reason No. 2.

The hard blue half hematized outcrop carbonate (rather red-short) is mixed with the bluish fossiliferous limestone, or "buhstone ore," so called, west of the Alleghany and in Ohio, together with the earthy carbonate ore of lower coal measures, for reason No. 3, and is supposed with good results.

The carbonate ore, last mentioned, is treated with good effect with the magnetic ore of Lake Superior, and with mill cinder for reason No. 3, making a good forge iron. All these are used with coke fuel as stated above. The tpyal, or theoretic proportion in parts, near and around Pittsburg, and, with a slight, say from five to ten per cent., decrease in limestone, for many miles beyond, is in coke = C, mixed ore = M.O, and limestone = L, as follows:—

50 C, 55 MO, 20 L,

with hot blast 600 to 650° Fah., moderate pressure 3 to 4 lbs. per inch, and moderate height stacks, medium size boshes 10 to 14 feet, this proportion produces a good foundry iron. We were informed, August, 1868, by Mr. W. T. Foote, the manager, at Port Henry Furnace, Lake Champlain, that the magnetic ores of that vicinity made a good rolling mill, close grain No. 3, mottled iron with anthracite from Lehigh basin, Pa. Proportions, December 18th, 1868, in No. 3 furnace, 3780 lbs. Cheever ore, 756 Barton ore, 980 limestone per charge of 3000 coal. Mr. Foote's report the week preceding was, 543,000 lbs. coal, 684,180 Cheever ore, 136,836 Barton, 177,380 lbs. limestone for 218 tons iron made. Average blast heat 843° Fah.

The Cheever ore, being very rich, is mixed with a leaner ore (the Barton Hill ore), containing a large per

cent. of silicate and alumina and some magnesia. The limestone found within about 400 yards of the furnace is a remarkably white stone, having largely the rhombic fracture of pure sparry lime carbonate, and containing many small hexagonal plates of graphite, the latter not sufficiently numerous to alter the action of the lime. All the gas from this furnace is utilized; the cup and cone system is used, and no gas whatever allowed to escape from the tunnel head. All the iron is used for rolling mill purposes, and is shipped to Boston, Massachusetts. At Oxford furnace, Warren County, New Jersey, we found a very good iron for nail plates, and used at the large nail factory at that place, made from a mixture of two-thirds Oxford magnetic ore, and one-third New Jersey Dover magnetic ore for reason No. 3. The iron has a tendency to red-shortness, however, from some sulphide which would be greatly corrected by the use of Franklinite ore to be had not many miles off, or perhaps more economically by use of the Oneida red hematite as the tendencies of some of that ore is to cold-shortness, and the two together would make an iron in which the evils of either ore would be neutralized.

Charges &c., for Fossil Ores.—These are interesting as managed in the region of Columbia and Montour Counties, Pa., where the results of furnace practice are very satisfactory in the nature of the iron, and the regularity of the working of the furnace. Nothing very imposing in form or size attracts attention so far as the stacks are concerned; indeed the furnaces are relatively small. In Bloomsburg, Columbia County, at the Bloomsburg Iron Company, Chas. R. Paxton, President, there are two stacks, one only 12 feet bosh 33 feet high; formerly it was 13 feet bosh with a crucible hearth of the usual formerly adopted form; temperature moderate, supposed about 400° , we should think not so high, pressure not more than 4 lbs.; coal, anthracite; the kind of ore has been described and analyses given under "FOSSIL ORES." The following is a full example of working:—

Daily History of No. 1 Furnace.

Date.	Charges for 24 hrs.	Soft ore.	Hard ore.	Coal.	Limestone.	Iron 2254 lbs. to ton.
December 13,	33	3000	1000	2400	2000	18½
" 14,	31	"	"	"	"	19
" 15,	33	"*	"	"	"	19½
" 16,	34	2400	"	"	"	20½
" 17,	31	"	"	"	*	15
" 18,	32	2600	"	"	1800	16½
" 19,	34	"	"	"	"	19
Total,	228					128
December 20,	29	"	"	"	"	15½
" 21,	28	"	"	"	"	15
" 22,	29	"	"	"	"	15½
" 23,	30	"	"	"	1900	15½
" 24,	31	"	"	"	"	17½
" 25,	30	"	"	"	"	16½
" 26,	30	"	"	"	"	15½
Total,					Total,	111

Daily History No. 2 Furnace.

Date.	Charges for 24 hrs	Soft ore.	Hard ore.	Coal.	Limestone.	Iron made 2254 lbs. to ton.
December 13,	29	3000	1000	2450	lbs. 2000	tons. 17½
" 14,	29	"	"	"	"	18
" 15,	27	"	"	"	"	18
" 16,	29	"	"	"	"	20
" 17,	30	"	"	"	"	19½
" 18,	29	"	"	"	"	17½
" 19,	30	"	"	"	"	18½
Total,	203					129
December 20,	28	"	"	"	"	18
" 21,	30	"	"	"	"	19
" 22,	31	"	"	"	"	19½
" 23,	30	"	"	"	"	18½
" 24,	30	"	"	"	"	19
" 25,	30	"	"	"	"	18
" 26,	31	"	"	"	"	19½
Total,	210				Total,	131½

In the above history of two weeks for No. 2 furnace, we see not only the methods of mixing ores and the proportions of charges, but the amount of iron made per

24 hours from each day's charge of ore. We see, that while the ore charge was uniform the yield of iron was not exactly uniform, making due allowance for the time necessary for the ore charged in at the tunnel head to descend to the hearth which would be about two days. The number of charges per week does not always exactly correspond with the number of tons of metal made, and although we have given but two weeks of each furnace, in looking over a longer time, the above shows a fair average. But when we take into account the effects of atmospheric moisture, variation in heat of blast or pressure, or of a little increased or decreased density of coal, the uniformity of the above daily yield is very satisfactory. The immediate reason of variation of charges per 24 hours may be found in more rapid fusing or fluxing due to more excellent and suitable proportions of earthy material, or to more open condition of the ore, or to that which we have spoken of very particularly relative to fuel, namely, difference of density and amount of carbon. The reason for allowing 2254 lbs. for one ton of iron in the pig is customary because of "sandage" as the pigs are cast in sand.

The iron made in stack No. 1 was not a foundry but a rolling mill iron, but after the change, on December 23d, to 1900 lbs. per charge of limestone, it became a higher grade, and continued some time between No. 1 and No. 2. The iron from these stacks have considerable reputation as uniform and strong. The asterisk in the above table indicates that the change was made at that series 33, and at the seventh charge of that series and so under Limestone.

At the other furnace in this town (McKelvy & Neal) Wm. Neal superintendent and proprietor, a variation from the above occurs, which is suggestive. Furnace, 14 feet bosh; 48 feet height to tunnel head top; tuyeres, three, with $4\frac{1}{2}$ inch nozzles. The general daily run of charging is seen in the following, giving both day and night "turns" or "shifts:"—

Date.	Charges.	Coal.	Soft ore.	Hard ore.	Limestone.	Iron
December 20,	18	2500	2400	2000	1600	9½
" "	18	"	"	"	"	10
" 21,	17	"	"	"	"	10
" "	19	"	"	"	1400	10
" 22,	17	"	"	"	"	10
" "	20	"	"	"	1500	11
" 23,	18	2400	2100	2300	"	11

Here the management of the charges is seen in attempting to moderate the too rapid consumption of material and sinking, by altering the coal element with other members of the charge. This may be done for other purposes, when, for instance, the iron is getting to be too fully charged with carbon, becoming more foundry, when forge is needed, or rolling mill iron. The pressure of blast in this furnace is low, about $3\frac{1}{2}$ to 4 lbs., temperature about 400° Fah., so we were informed, but on examining the hot blast stove we should think that the temperature, during the three days we were there, did not rise to so great a height. The stove is upon the ground and the gas drawn down by a stack. There are very few furnaces which work so satisfactorily as this so far as regularity of produce is concerned. We were informed by Mr. Neal that he had not been troubled with a scaffold for nine years. The proportion of iron to the coal is as 1 to 2, or 1 to 1.98. Diameter of steam cylinder 30 inches, 6 feet stroke.

The value of the ore for iron may be seen by the following data furnished us at the furnace :—

For week ending December 26, 1868.

Coal . . .	637,500 lbs.	275½ tons, gross.
Ore . . .	1,077,000 "	480½ " "
Limestone . .	379,700 "	169½ " "

Product : $139\frac{1}{2}$ tons iron, gross.

$1\frac{98}{100}$ coal to the ton of iron.

$3\frac{44}{100}$ ore " "

$1\frac{21}{100}$ lime " "

At Danville, Montour County, a somewhat improved practice is pursued on the truly scientific idea of quali-

fying and modifying those hurtful ingredients previously existing in the native, or home ores, by a mixing with certain foreign ores, that is, foreign to the county and different, radically, as will be seen in the following, which is worthy of notice, as the attempts in modifying the effects of the fossiliferous ingredients have been successful. The iron is made for the rolling mill and used for rail, giving great satisfaction.

Report of the Pennsylvania Iron Works, week ending June 20, 1868.

BLAST FURNACES.

	Stock used.							Product of pig iron.
	Coal	Lime stone	Cornwall ore.	Block ores	Soft ores.	Artif. ores.	Lime-stone ores.	
Furnace No. 2,	tons.	tons.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.	tons. cwt.
“ No. 4,	286	159	154 6	61 6	61 6	30 13	...	122 0
	210	187	24 4	48 8	169 10	...	48 8	104 9
Total,	...	...	.....	.....	.....	...	...	226 9

The fossil ores of these counties, Montour and Columbia, are peculiar, and require different working from that pursued among the New York fossil ores (Oneida Co. and elsewhere). But their similarity to ores farther west and south may enable some to exercise judgment, successfully, in adopting their charges to the nature of their own fossil ores. Nevertheless, we have seen the fact abundantly illustrated, to which we have already alluded, that the same manager may use, in a different furnace, the same charges, and yet may not arrive at precisely the same results, anymore than a man may read with the aid of spectacles when he never read before.

Charges, &c., for Red Hematites.—In the region of the compact red hematites of N. Y. no ores seem more notable than those of the Sterling, Shurtliff, and Rossie mines, but there is no finer ore than that of the Sterling mines, Jefferson Co., N. Y.

An interesting feature of these Sterling ores is found in the beautiful sulphide of nickel, acicular crystals,

frequently in radiating tufts in cavities of the ore, very brilliant, brass-like, and brittle; composition—

Sulphur	. . . . .	35.1
Nickel	. . . . .	64.9

There are also found, frequently, mamillary incrustations of carbonate of iron and micaceous red hematite (called wrongly, by some, "black oxide"). The following analysis of the Shurtliff from an extra fine specimen gives:—

Moisture	. . . . .	6.16
Silex (insoluble 15.15, soluble 2.60)	. . . . .	17.75
Peroxide of iron	. . . . .	62.45
Alumina	. . . . .	10.70
Lime (carbonate)	. . . . .	.87
Magnesia (carbonate)	. . . . .	.22
Sulphur	. . . . .	2.43
		<hr/>
		100.58
Metallic iron	. . . . .	43.71

This ore, in the leaner samples, would form a good flux with the Sterling ores, which are compact red hematite. The analysis was made by Mr. H. D. McKnight, of Pittsburg, in our laboratory, and, as we have said, from rather an extra fine sample of the ore. If, however, this was an average sample of all the ore, the amount of soluble and insoluble silex would require considerable lime, and of a good quality, to flux it, especially with the amount of alumina. The 2.43 per cent. sulphur, with proper mixing, would hardly cause the iron to be red-short, as in practice considerable of the sulphur is always eliminated in the roasting, or heating, before melting.

It, however, varies much in the same bed, and some specimens, we have, contain a large amount of alumina, and would yield little iron. The Sterling ore, however, is almost absolutely free from sulphur, with a higher per cent. iron, and makes a far superior iron even by itself. In the practice by Mr. Sterling care is taken even with the kind of charcoal. He uses generally two-thirds hard wood, beech and maple, and one-third hemlock and spruce. A charge consists of 20 bushels charcoal;

550 lbs. usual ore (with all hard coal, 625 lbs.); 50 lbs. lime. The Shurtliff ore is used as a flux, usually one-eighth. Iron from the Sterling ore commands a higher price than that from the Shurtliff or Rossie ores. The furnace for the Sterling ore is small, hence the charges are small. Size: 32 ft. high, 24 in. diam. of bottom of the hearth, 26 in. across tuyere; 9 ft. across the bosh; only one 3 in. tuyere. Cold blast and about $1\frac{1}{2}$ lb. pressure. The ore works easily.

At Rochester Iron Works, N. Y., Mr. Horton has succeeded in making a large yield of a strong and tough iron, which we have had the opportunity of testing in the pig, but only from one cast. His practice is to make neither coal, nor blast constant, but to vary the three elements, coal, temperature, and pressure, to suit the conditions of his furnace. His ores have been Lake Superior red hematite, a great proportion of which was micaceous red hematite (see its nature under Commercial Ores) and the fossil ores, also red hematite, of N. Y. (see Clinton Co. and Oneida Co. Ores). In mixing these ores one-half to one-half, or three-fourths Lake Superior to one-fourth Oneida County fossil (of the kind described as Fish Egg ore) a very superior iron for foundry purposes has resulted. These Works use Luzerne County anthracite—high temperature of hot blast (about 1000° Fah.) and pressure moderate.

Mr. Horton's Report for March, 1869, was:—

	Tons.	cwt.	qr.	lbs.	
Coal used	1341	10	1	12 = $29\frac{3}{4}$	cwt. to the ton iron made.
Ore . .	1867	4	3	13 = $14\frac{1}{4}$	" " " " " "
Limestone	602	18	2	3 = $13\frac{1}{4}$	" " " " " "
Iron made, $902\frac{1}{2}$ tons.					

Charges: 4 barrows coal = 500 lbs. each; 4 do. ore, 675 lbs to 700; 2 do. limestone 445 lbs. to 462, as the case may require.

This, with what we have elsewhere said on this furnace and others in New York, will suffice upon the red hematite charges, as it sufficiently covers the principles involved and, in great degree, the practice.

In Dutchess County, N. Y., Mr. D. B. Martin makes an excellent charcoal iron for car wheels from the *brown hema-*

tite of the general Salisbury Range, at Dover Plains. The peculiarity herein is that he does not mix his ores. Some care is exercised in respect to the physical condition of the elements of the charge, but a very good iron is made under the following charges: 30 bush. charcoal, $12\frac{1}{2}$ gross cwt. ore, 180 lbs. limestone. The furnace stack is 34 ft. high, has 9 ft. bosh, 42 inches diameter at tunnel head. The hearth has room larger than at first building and is about $4\frac{1}{2}$ ft. diameter. The average pressure of blast is from one-half to three-fourths lbs.; not generally over one-half lb. per sq. in. The irons are graded thus: No. 1, soft; 2, little below a chill; 3, chill about one-fourth inch; 4, chill about one-half inch; $4\frac{1}{2}$, chill about three-fourth inch; 5, mottle; 6, white.

Magnetic Sands.—The charges for ores of this nature have not, as yet, been determined by any practice upon the large scale, but as we have seen sand of this nature, and of a very fine quality, of which it was said that a large amount of it could be obtained from regions not far off, commercially speaking, it may be well to refer to what we have said upon the subject elsewhere, and add that these sands have hitherto been worked most successfully in the Catalan forge, by mixing them antecedently with the flux, lime, and small portions of clay, and forming them into balls; in this way they may be handled readily.

Very lately, we have seen a sample of magnetic sand, which exists in large quantities upon the southern shore of Long Island, N. Y. That which we have examined is of an excellent quality, being, when separated by the magnet, entirely free from sulphur, or phosphorus and containing but little titanium. Much of it is not separable by magnet, and doubtless, in places upon the same shore, varies in constitution and may be found highly titaniferous, as is much of this variety of ore.

Titaniferous Ores in the Blast Furnace.—In case these ores are to be treated with in the charge, either as just described, or in other form, the following may be satisfactory, the correctness of which is vouched for by Henderson of Player & Henderson. We would say, however, that ores containing so much titanous acid as the analysis

below exhibits, are extremely rare in this country, so far as known at the present. Some sands, however, approximate this amount so far as 14 per cent. of titanitic acid can make them do so, but there are no commercial ores at present in the market with this quantity, whatever there may be in the future.

Mr. Henderson writes us that these ores are now successfully used in Norton, England, on a plan patented by John Player, of New York

The ores are found in Norway and taken to England. They contain, as in this analysis:—

Peroxide of iron	22.63
Protoxide of iron	28.96
Protoxide of manganese . . . . .	.56
Titanic acid	40.95
Alumina	2.11
Magnesia	4.72
Silica . . . . .	.42
	<hr/>
	100.35

They are worked in small furnaces with 1000° temperature of blast. 2 tons of coal to 2½ tons ore and 15 cwt. of limestone, and about 10 cwt. of basalt rock.

The iron becomes titanized, and is found to be exceedingly strong, and is used in Europe for armor plates, commanding three times the price of ordinary pig iron. The tensile strength of the resulting wrought iron when puddled, is about 52½ tons to the square inch. There is very little carbon in the pig metal produced, and being almost steel, in puddling it requires but half the time of ordinary pig metal.

Physical Condition of Slags.—It may be worthy of remark, that much may be learned of the condition of the furnace, by the character of the slags both while they are flowing from the cinder hole and after they have become cold. But we have known iron masters to miss the mark widely by supposing that because a cinder, at some iron works they had visited for the first time, was of a darker shade than their own and frequently capped with a dark skin or layer, that therefore the furnace was making an iron of inferior grade to their own. A shade

of difference may exist in two slags, both of which may cover irons, so far as openness and evenness of grain are concerned, identically the same, and the peculiar shade may be due to certain elements in the fluxes, coal, or ore not altering the appearance of the iron. Charcoal, coke, and anthracite slags differ slightly for the very same kind of iron, judging from all that appears to the eye; but it must at the same time be kept in mind that there is a limit beyond which this peculiarity is not found to extend, and the slag will then show very nearly the nature of the iron made. Practice and a large amount of observation will give great precision in respect to this method of forming an opinion.

While an opinion may be formed upon cold slags, it is also true that much may be learned from hot slags; in the liquidity, the scintillations of iron, the brightness, the shade of color, and smell, each will, respectively, aid the manager in determining the grade of iron as to carburization, the losing of iron, the degree of heat in the hearth, and the presence of other metal and metalloids in the furnace. Herein, also, it may be said, as we have suggested above, that much of this information is relative and local, and depends upon the conditions of one day as compared with those of another day, and absolute facts are to be learned by constant observation at one and the same furnace under the charges of the same materials.

The yield of metal per week does not *always* depend upon either the skill of the manager, or upon the excellence of the furnace. Some managers have boasted of their furnace-yield with a confidence founded upon the fact that their stacks, being only so many feet in diameter, produced so many tons per week more than were produced at another stack having greater diameter, while if the nature and causes of the yield were truly known to themselves they would have seen that the larger stack, making less iron, was worked perhaps more skilfully than their own, and that the probabilities were, that if the managers were exchanged, all material being the same, the furnace differences would be vastly increased in favor of the skill of that manager whose furnace was

making less iron. A large furnace may make no more iron than is to be found in the charges per week. If the charge of 1000 lbs. contains only 30 per cent. iron, then 58 per cent. of the ore is gangue. Every one per cent. of gangue, as our American ores are generally constituted, requires more dead flux (that is, flux without iron in it) to give a proper cinder, and every increase of material, other than iron, requires more heat, more coal, more time. A large bucket will overflow with no greater stream of water than will a tin cup, if the supply, to either, is from a stream yielding at the spring, only a gallon an hour. And the same is true as regards the tunnel head of a furnace; if the charges are 20 cwt. and that amount contains only 30 per cent. of metal, then, provided that every other circumstance be properly proportioned, or, as it is said, "all things being equal," it cannot be that the furnace should yield as much metal as when the ore contains 40 per cent. iron. Hence it frequently occurs that furnaces, antecedently making a certain amount of iron per week, have, upon changing nothing but ores, suddenly increased, or decreased, in amount of yield, with neither increase nor lack of skill on the part of any of the hands, or the managers, concerned. Of course these facts are more favorably apparent when the ores are more open, that is, less compact, when the limestone is purer, especially when free from magnesia, or any other substance making it less fusible, and when the coal is more suitable.

The above facts are true in relation to yield of metal per day when there is no altered condition except in ore alone. It necessarily follows that, when we *can have a choice*, the less compact the ore, and the higher the per cent. of iron, the more economical are the results, all things being otherwise equal. And, herein, the judgment of iron companies is to be exercised, for it may be more profitable, regarding the situation of the furnace, to work an ore yielding only 24 tons of metal per day, than to "freight" an ore, from a distance, yielding 30 tons or more per day. There are many circumstances and many elements in the economies of a furnace worth more attention than simply the yield of iron per day.

While these facts are worthy of attention, it is also true that skill on the part of the manager may cause a furnace to yield more metal per day from the same ore than could possibly be obtained without that skill. The particular points whereat such skill may be exercised are to be found in the choice of coal, the purity of the limestone, the proportions, the number and the nature and condition of the ores mixed and the particular proportionate amounts of coal, mixed ores and lime, or other flux, forming the aggregate charge. These are the important elements, so far as charges are concerned. Although, in the making of good iron, either forge, or foundry, white, or gray, or intermediate, the blast, in its temperature, amount of air-supply and intensity of pressure, may modify quality, yet nothing economical, or skilful, can be accomplished where the charges are badly engineered.

Practical Remarks on Charges.

It is, however, very evident that the charge of a furnace, after all these general principles have been understood, must be regulated and modified by circumstances entirely local—such as the pressure, temperature, and quality of blast—the height of stack which, especially in coke and charcoal furnaces, may determine the nature of the iron from the pressure upon weak coal and the consequent interruption of the blast. But of all causes of trouble, the chief is from bad mixing and distribution of material at the tunnel head. Good “fillers” are of great value; care as to the size of the ingredients of a charge, and proper roasting of the ores are important.

On our first visit to Europe we had our attention particularly drawn to the fact that great care was exercised in little matters in the most successful furnaces on the continent and in Great Britain; but on a second visit during 1852 and 1853 our acquaintance with a practical and intelligent Swedish gentleman furnished us with an opportunity to inquire into the minutiae of certain preparatory work of this nature, and the conclusion was, that, although such extreme painstaking might not be

considered practicable in our country, the finest irons of Sweden, and of other parts of Europe, were the results of the utmost care in selection of ore—in the roasting—in the sizing—the careful distribution of the ore by means of shovels and the careful treatment in some of the after-management of the furnace.

The first step then is an analysis of the ore: for this purpose an intelligent man should select the samples and should go through the toil of picking out about 50 pieces of all varieties readily observed in the mass of many tons of average ore, for, while for the chemist alone, any small specimen might be sufficient for a perfect analysis, that sample, selected from 50 specimens of small size, treated as we are to show, will be more likely to reveal what one specimen would not, namely, the furnace value of that ore in the mass. After this selection of specimens the manager should have some eight or ten pounds of this ore broken down, to very small pieces, on a slab of iron; have it spread out, away from sunshine and winds, marked out into twenty or more rectangular divisions, and, beginning at one end of the heap, take alternate divisions and throw them into one heap, taking the last pinch of dust carefully up with each selected pile. The next sampling must be done by spreading all out again evenly and into a square, or circular mass, dividing it into four equal parts and taking diagonally opposite parts; this operation must be carefully repeated at least ten times, and if ten pounds of ore were taken at first and treated carefully in that way, the manager may send one of the divisions, or one-twentieth, or half a pound to the chemist with considerable confidence that the analysis will be a fair representation of the elements of the original ten pounds. The method of sending any part of a piece of ore which takes the fancy of one's attention, is truly a fancy method of procedure, and almost invariably misrepresents the furnace value of that very ore.

As an illustration of the infelicity of this method of picking out strange and unusual pieces we may give the following: We were once requested to make an analysis of some ore of a compact brown hematite nature; we

did so, and found it practically free from sulphur. We were informed that another analysis had been made and the report was returned to the company, announcing the existence of considerable sulphur. The chemist was a careful man, but as the company thought it of importance to examine further into the difficulty we visited the heap with the specimen analyzed by the chemist in hand, stating that we believed it to be improbable that half a dozen such samples could be found in a ton. After considerable overhauling and examination by three of us only four fragments could be found in several tons. These fragments contained a small (2.26) per cent. of sulphur—the ore, aside from these unusual samples, not showing a trace of sulphur. Had 50 specimens been selected and these two thrown in and sampled, although even this would have been an unfair representation, yet the sulphur would not have amounted to any properly recognized trace in the analysis; for, supposing that it was equally divided in quantity, that is, 2 parts of this ore, or sulphuret, with 48 parts of the other ore which was free from sulphur, then, when combined, it would have given 0.04 per cent. Now as two-tenths of one per cent. in pig iron is of no injury to the iron, of what injury would only four hundredths of one per cent. have been in the ore? Yet this mistake came nigh involving the ore-company in the loss of many thousands of dollars, with the addition of some unhappy feelings, which latter, not having any money value, in some markets, may be thrown out of the calculation.

What has been said of ore may also be said of the limestone. This must be sampled in the same way when sent for analysis, if the parties desire any conclusive, honest, and thoroughly satisfactory knowledge. The coal should be tested for sulphur where there is any reason for supposition that it exists largely. Also, when “bony” or slaty, if to any large extent, it will certainly alter sensibly the effects of the furnace products, as we have stated, at large, elsewhere.

As an illustration of the importance of knowing the nature of limestone, we may say that in one Penn. furnace using anthracite and limestone, the latter from the

vicinity, and therefrom making a very good foundry iron for several years, the iron suddenly changed to a lower grade, so that no foundry iron could be made for months. Upon examination it was suggested that the limestone was at fault. It was accordingly carefully examined and found to be of a new variety containing a very greatly increased amount of magnesia, when compared with what had previously been used:—the stone alone was changed and the furnace returned immediately to foundry iron. The manager of the furnace, who is part proprietor, informed us that he would give a large sum for the practical skill of a chemist, in other words, there was in this instance some decided appreciation of the often contemned claims of scientific investigation. It is necessary, therefore, to begin upon a chemical knowledge of the ores, fluxes, and even the purity and impurities of the fuel. But this is not sufficient to success in charges, although it is the foundation of success to every economical manager who does not wish to waste time and money in experiments made in the dark, as there will remain, after all his knowledge, quite room enough for experiments promising useful information, without entering upon those which are certain to prove vexatious and expensive failures.

The next important matter is the roasting. As we have already spoken of this, we shall pass on with the remark that there will be, in a few years, as there is already in many places, no doubt that a large element of trouble in iron manufacture is to be found in the neglect of, or the careless method of, roasting. Too rapid roasting seals up the outside "skin" of the ore, so to speak, and, as in silver metallurgy, it is the cause of millions of loss in silver, so it is the cause of loss in iron, in the retention of injurious volatile substances, the elimination of which substances would be followed by easier reduction and better metal, and hence by greater saving. But we shall now only refer to the past pages on the methods of roasting.

Next in importance is the distribution of the charges. And under this head may properly be made the remark

that the method of tumbling into the tunnel head such unequal masses as are frequently thrown in, must cause great unevenness in the cast. This remark has reference to either quantities of slack and fine coal, or to large lumps of coal, to fine dust ore or large lumps of ore, and the same may be said of limestone. Great pains are taken in some most successful furnaces to reduce the ore, coal, and limestone to certain uniform sizes, or, to what is nearly equivalent, to certain uniformly distributed masses where fine ore must be used, so that the same general result is nearly reached, though no furnace will work so well under dusty, or fine, ore as when made more open by the use of larger pieces.

The method of distributing charges around the tunnel head in alternate doors is a good method. This has been described in speaking of tunnel heads of furnaces. But after all, none but good fillers and men of judgment should be put at the tunnel head, for the better distributed (and that is the more evenly distributed) is the charge the more satisfactory the working. There can be no doubt but that some of the cone and cap arrangements used in British furnaces, and continental ones also, do distribute the ores well and with very satisfactory results, and yet there are furnaces where care and judgment on the parts of the fillers do result in excellent distribution, even without any such arrangement.

Next in order is the pressure and amount of the blast. Considerable differences in effect upon the iron do follow differences in the pressure and amount of blast. We have been informed by Mr. David Thomas, that experiments, in which as many as 18 to 20 tuyeres were tried in one furnace under his observation, have been followed with such poor results that the number had to be decreased one-third, or one half. The same has occurred at Scranton, Pa. Nevertheless, more than three tuyeres were found necessary at either place. The happy mean depends upon size of nozzle, pressure, and temperature of hot blast. The sizes of nozzles vary from $1\frac{1}{2}$ to 4 inches according to width of hearth. There is no doubt that much power is usually expended upon mere

pressure of blast which will be economized at some future time. Not that less air is demanded when hard coal is used than when coke and charcoal, for more carbon consumed requires more oxygen to consume it, but is it necessary that that amount of air should be forced through three or four tuyeres, or ten or fifteen, under the pressure of six, or as at some furnaces on the Lehigh, eight pounds per inch? This is the practical question. Some other and more economical method of applying a sufficiency of oxygen to the coal seems to be demanded and will yet be invented, whereby greater heat absolutely, or the equivalents of greater heat, with lower average pressure of blast, will yet be attained.

In recording charges, in some furnaces, a charge-board is used and the simplest method of recording amounts, alterations, and barrow loads, must always be adopted. The following plan of marks, or symbols, and their meanings is the best we have seen:—

For ores	$\left\{ \begin{array}{c} \frac{1}{T} \\ T \end{array} \right.$	means ore added,
		" ore taken off.
For limestone	$\left\{ \begin{array}{c} \textcircled{+} \\ \ominus \end{array} \right.$	" limestone added,
		" limestone taken off.

The board is divided right and left by a vertical line; the left is marked D and the right division N for day shift and night shift; and between the two and at the top No. 1 or No. 2 as the number of the board may be.* The scales are always best arranged when they weigh only the whole amount at once and without any possibility of alteration to any other amount by any one. Such scales are used at many of the iron works and of this kind a very neat arrangement of furnace scales is made whereupon the words ORE, STONE, COAL, appear near corresponding index points on the same scale upright so that the most careless weigher need make no mistake.

* This is the plan at Catasaqua Crane Works.

A very neat method keeping a full account of charges may be seen at many of the furnaces, but of this we need only say that the bookkeeper must suit his form to the contingencies of his charge, that is, where ores are numerous, and not simple, he must use more columns, and where ores are unmixed, or few, he must use less; hence this must be left to the ingenuity of the bookkeeper.

Unusual Furnace Deposits.—Some of the iron ore used in the Acklam furnaces, England, contains zinc. There is no analysis of this ore given; but there was exhibited at the Paris exhibition a small quantity of a white powder collected in their gas flues, of which the following analysis was given:—

Protoxide of iron	14.22
Oxide zinc	10.48
Sulphide zinc	13.70
Alumina	8.20
Lime	12.32
Magnesia	5.03
Chloride of silicon	4.74
Ammonia	0.70
Thallium	trace
Sulphuric acid	3.18
Free sulphur	0.17
Silica	22.60
Carbonaceous matter	4.50
	<hr/>
	99.84

The editor of Engineering says that this is an analogous production to the fumes of zinc collected at some of the Prussian blast furnaces, and sold at a very remunerative price by the iron-masters there. An analysis of that dust, also furnished by the exhibitors, shows that zinc forms a very important part of its composition. It is very probable that the utilization of this powder, which collects in the blast furnace flues in great quantity, and at present is not made use of in any way, may be found equally profitable, as has been the case in Prussia. We have seen at the Königshütte, in Prussian Silesia, the whole tops of the blast furnaces covered with similar

white dust, and we have been informed that it is collected and used for the manufacture of oxide of zinc, which, in fact, is one of its principal components. This is a very profitable operation at the Königshütte, and it is not unlikely that it may turn out equally advantageous if taken up in Cleveland.*

The above facts have led us to examine the so called "cadmia," or sediment found in the hot blast stoves on the Lehigh and in New Jersey furnaces, and with the same results. Zinc is found in almost every furnace on the Lehigh. A very beautiful caking powder occurs at the Oxford furnace, Warren County, New Jersey, the only place in that county where there is a furnace. At Durham furnace, eight miles below Easton, Pa., on the Delaware, nearly 5 per cent. of zinc showed itself in some of this powder which we gathered out of the hot blast at that place. Our examinations have not been made beyond these places, although we are interested in collections from various furnaces. Analysis cannot be made in time for notice in this work, and these ashes (or wrongly termed "cadmias") are taken, thus far, from furnaces using ores from the general region of the zinc deposits of the Saucon valley, or the New Jersey Franklinite, and hence may be supposed to contain zinc, although it is not discoverable in any of the ores by an ordinary analysis.

Titanium, in the crimson cubical form of cyano-nitride of titanium, has been found, frequently, in the Lehigh furnaces, in the crevices of the hearth, after the furnace has been blown out. We have some specimens from Crane Works. The ores containing titanium are from Morris Co., N. J. We have, also, some pig iron colored purple by the presence of titanium taken from the same works. It has, necessarily, no effect upon the iron under these circumstances.

Various crystalline forms of slag used to appear more frequently, before the improved methods of carrying off the slags were adopted and when the slags were allowed

* Engineering, June 21, 1867.

to cool in sand-holes, as is indeed the method still adopted in some places, where such crystals are formed at present. Mr. Thomas Hunt, of Catasauqua, presented us with a specimen of an extremely fine and glossy tufted substance, which proved to be an asbestus, (containing SiO_3 , MgO , CaO , FeO) taken from the cast house, and which was found entangled in some slag at the juncture of the pig and sow immediately after casting. The magnesia of this asbestus came, doubtless, from the limestone. At Cooper's Furnace, Phillipsburg, a very interesting series of glassy crystals of *diopside* appeared among the slags, a mineral which is composed of the same elements as asbestus but in different proportions and form, and with less iron in this instance.

At Columbia, Lancaster Co., beside the olivine in the salamander, which has been described elsewhere, a mass of graphite was given us so nearly resembling lead that it was supposed to be that metal until it was found that no heat would melt it.

Peles hair, or furnace glass, sometimes appears as white as wool and as fine, blown out from the cinder-hole and lodging against the rafters of the cast house. This is supposed to be a sign that the furnace is working badly, but it is only because of the viscid condition of the slag and the fact that at a certain point the slag was caught up by the blast and spun out. The same glass may be spun under the same condition of slag, by means of a stick thrust adroitly into the slag and swung around the head. So far as the viscid condition of slag is a sign of bad working, this glass may be taken as a sign, but it is one, in itself, of very little or no importance.

CHAPTER VII.

HOT BLAST OVENS.—WASTE HEAT.

THE forms of some furnaces have been somewhat modified at the throat, in view of the utilization of the combustible gases, and the only departure from the uniform curve reaching upward to the margin of the top of the furnace, or throat, might be made in view of this purpose of utilization. This appropriation of the "waste gases" had been extensive in America before the same economy had prevailed, even to a moderate extent, in Great Britain, although upon the continent it had been introduced extensively in some districts. It is remarkable, that so lately as 1864, Dr. Percy, writing in regard to the application of the hot blast, should have ample occasion to say of British masters: "I have felt no small commiseration for ironmasters who still pursue the old plan of using solid fuel," and it is remarkable that in the late edition of Mr. Truran's Works, 1865, nothing is given in the text as to the vast improvements in the hot blast working of iron, but the prejudices of Mr. Truran are transmitted from edition to edition with the exception that at the end of the final chapter "on the employment of furnace gases" a short note is subjoined stating that ironmasters differ with Mr. Truran, and that "the utilization of the tunnel head gases has steadily progressed during the last few years and the blast furnaces at the Dowlais Works have been recently fitted with apparatus of the most complete description for collecting and burning their waste gas."

The following preliminary remarks are interesting as historical, and may introduce us to the modern method and improvements invented since the time of Mr. Overman.

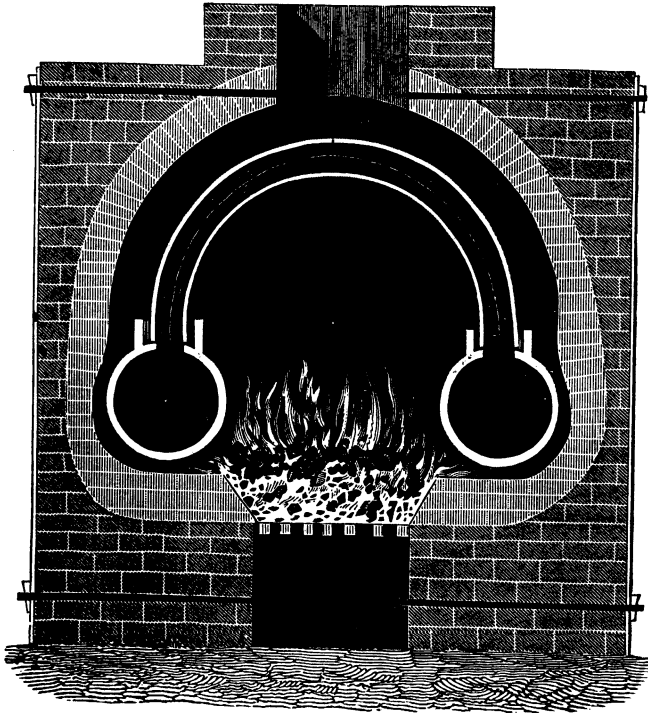
[The apparatus for heating air before it is brought in

contact with the fuel, is very simple, and the principle it involves easily understood. The object we seek to secure in the construction of an air-heating oven is that the air shall be heated only to a certain degree; for we shall find that, from any degree of heat beyond this, no advantage is to be derived. Further, an apparatus must be of such a form as to heat the pipes uniformly; for, if the fire plays too much on one place, the metal pipes are soon injured. This apparatus, on account of its simplicity, admits of a variety of forms; but in general, it is settled that the horizontal pipe is the most effectual with respect to economy of fuel, though it needs modification on account of the material from which it is made. The horizontal form of the pipe is the best, for the same reason that the round and horizontal is the best form of the steam boiler; that is to say, by means of this form the greatest effect of the heat applied is secured. Air-heating pipes should be made of gray cast iron, because of the fusibility of other metals, and of the facility with which wrought iron oxidizes, being in contact with oxygen on both sides. Nevertheless, cast-iron pipes are very heavy, and they will bend, and finally break, by their own weight, if laid horizontally, and heated in that position. Pipes of a vertical form will resist the influence of the heat better than those of any other form, but they are thought to be less favorable conductors of heated air. Those who have attempted to make improvements on the air-heating stove have sought to unite the advantages of the one with those of the other. Most of the forms now in use are based upon this principle.

a. Air-heating stoves were formerly reduced to two principal forms; the circular pipe, and the vertical, or more or less inclined pipe. Fig. 99 represents a vertical section of one of the earliest air-heating stoves with round pipes, which scarcely requires explanation. The diameter of the round pipes is generally three inches inside, and that of the two straight and lower pipes, fifteen inches or less, according to the quantity of air which is said to be passed through it. The cold air

passes in at one end of one of the lower straight pipes, and out at the opposite end of the other pipe, which is

Fig. 99.

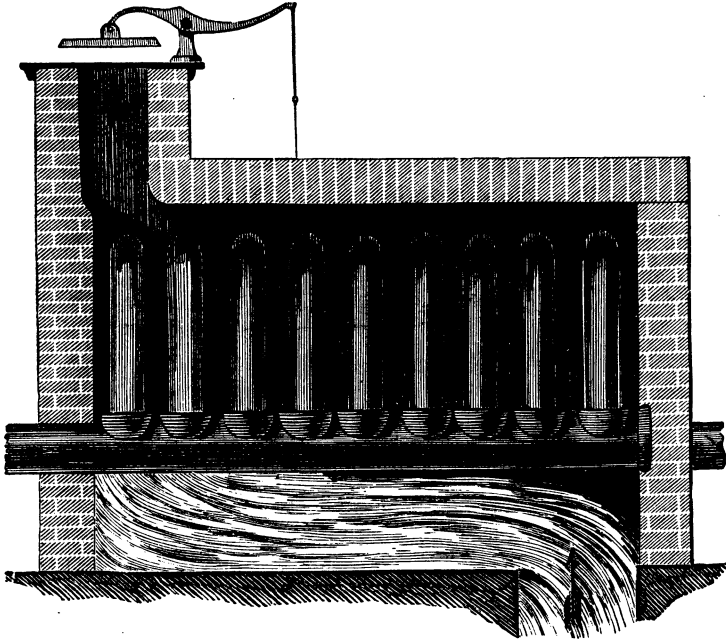


Hot-blast apparatus.

more clearly shown by Fig. 100. The apparatus is here assumed to be on the top of the blast furnace; therefore, no fireplace is seen. Fig. 99 shows a grate; hence, the apparatus is designed to be heated by separate fuel. That shown by Fig. 100 is heated by the waste heat of the furnace. The number of round pipes is increased or diminished according to the amount of air to be heated. The distance between the two straight pipes is generally four feet, which will make the distance of the round pipes about five feet. The vertical pipes are placed as near as possible to each other; sufficient room is left for the passage of the flame from the furnace,

which does not require more than one and a half or two inches. In the mason work are several small doors, by

Fig. 100.



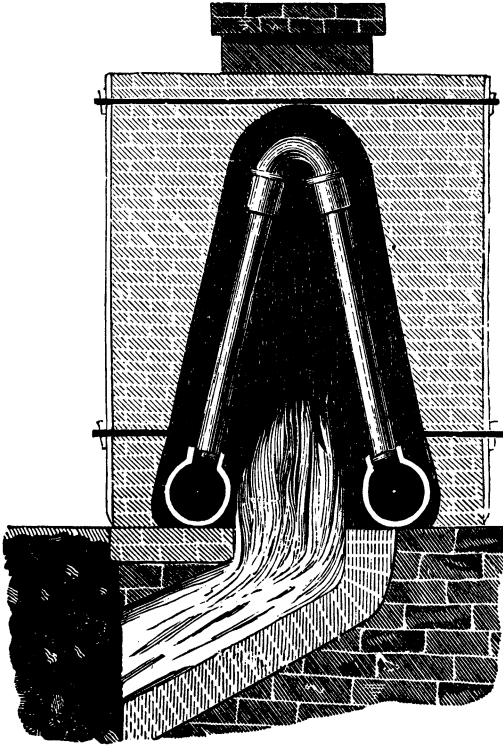
Air-heating apparatus—longitudinal section.

means of which the pipes may be cleaned, for on the surface of the latter a large quantity of dust and carbonized ashes is, in the course of the operation, condensed. Unless the pipes are frequently cleaned, they are liable to burn. More or less draught may be given, and more or less heat generated, by the damper on the chimney. The round pipes are set on each side in sockets, and well secured by careful cementing.* If we wish to make the best use of the heat, the grate, or the entrance of the flame, should be put on at that end of the apparatus from which the hot blast is let off.

* Sal ammoniac of the shops and iron filings mixed—a good receipt is salamm. (saturated solution) and iron filings mixed with the solution till a pasty mass is made.

b. In Fig. 101, the other arrangement of the heating pipe is represented. It differs in no respect from the

Fig. 101.



Hot blast, heated on the top of the blast furnace.

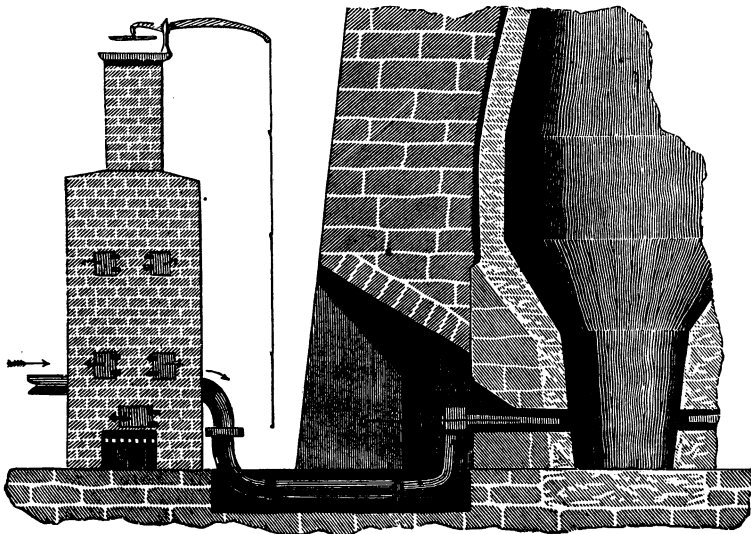
one just exhibited, except in the fact that the heating pipes are straight and set almost vertically, connected at the top by a short curved pipe. The straight pipes are frequently from six to eight feet in length at large furnaces; diameter inside five inches; metal one inch thick.

For small charcoal furnaces, an apparatus five feet long, consisting of eight pipes, is sufficient. At large anthracite and coke furnaces, we meet with an apparatus of thirty and more pipes for each furnace. No general rule with respect to the number of pipes, and the extent

of surface required, can be given; but conclusions derived from experience prove that a surface from three to four feet square is, when exposed to the heating flame, large enough to heat an amount of air sufficient for one ton of iron per week. The heat, in the interior of such a stove, is not very great; but the furnace, and frequently the whole apparatus, are lined with fire-brick. This is more durable, and saves more fuel than red or common brick. Heavy brickwork is very advantageous at hot-air furnaces, for changes in the temperature of the blast should be provided against.

c. At a blast furnace, where hot blast is employed, the tuyere cannot be left open around the nozzle. We are thus deprived of the means of getting at it directly. As it is necessary that the tuyere should be cleaned, an arrangement is made to get at it from the cap of the pipe near *a*, Fig. 102. A small hole in the cap admits

Fig. 102.



Hot-blast stove, air-pipes, and tuyere poker.

a three-quarter inch round rod, which is pushed in until it reaches the tuyere. This hole is closed by a short iron stopper. The cap *a*, on which the nozzle is fastened,

must be light and easily movable, above the valve; for, as we have stated, some work is necessary to be done at the tuyere. The cap and nozzle should be light, and movable with facility, and therefore the best material from which they can be made is sheet iron. In case the heating-stove is at the top of the blast furnace, the blast pipe may be led from above to the tuyere. This is advantageous where but one tuyere is to be supplied; but where two or more tuyeres are in the furnace, it will be found preferable to lay the pipes below the bottom stone as indicated in the last cut. In case there is no surplus of heat, and we wish to preserve, as much as possible, the heat in the blast, the hot air-pipe, leading from the stove to the tuyeres, may be packed in sand, and laid in a wooden box; or, it may be surrounded by a coating of loam. The pipes closest to the fire must be secured against the violent action of the flame, by a protection of brickwork or fire-clay. It is advisable to have a direct communication between the tuyere and the blast machine; cold blast can thus be led directly, into the furnace when it is required, without passing through the heating stove.

d. In the cap of each nozzle there is a hole, to which the manometer, an instrument for measuring the pressure, *ma-nom'-eter*, from *Greek*—*manos thin*, and *meter measure*, is attached; this enables us, by introducing a thermometer for a short time, to measure the lowest degree of heat of the blast. The thermometer must be sufficiently long to indicate the degrees of heat below the boiling point of mercury; a greater length would be superfluous. Glass instruments are very liable to be broken, particularly at furnaces; and as it is a matter of considerable importance to know the temperature of the blast, a more practical means of measuring heat, namely, by alloys of metal, is resorted to. A small quantity of such a composition, or of pure lead, is put into a small vessel of copper or iron, which is fastened to a thin wire, and let down into the centre of the blast pipe. After obtaining a composition which melts at a certain temperature, no further experiments are necessary; and

such a test may be applied when a doubt arises in our minds as to the heat of the blast. For practical purposes it is unnecessary to know exactly the degree of this heat. An approximation to correctness will, in this case, answer every purpose. Pure lead melts at 470° ; mercury boils at 660° ; tin melts at 380° , tinner's solder at 410° , type metal at 350° , and a mixture of type metal and tinner's solder at 300° . We shall annex a few alloys, which may be used to measure lower temperatures; but with the caution that the melting point of the alloys is somewhat raised after each experiment. A mixture of five parts of lead, three parts of tin, and eight parts of bismuth, melts at the heat of boiling water, or 212° . The addition of mercury makes it still more fusible. Three parts of bismuth, one of lead, and one of tin, melt at 200° . Bismuth melts at 480° ; but its alloys are very fusible. With the addition of bismuth to tinner's solder, all the degrees between 200° and 500° may be produced. Nevertheless, a mercury thermometer, inclosed in a metal capsule, and suspended on wire, to prevent the contact of the glass and metal, is the best and easiest method of measuring the heat of the blast. Other plans of pyrometrical measurement will be stated hereafter.

Theory of Hot Blast.

The effect of the application of hot blast is threefold: First, it saves fuel in the direct proportion of the temperature of the aliment to the temperature of combustion. Secondly, the supply of hot air to smelting operations increases the reducing power of the gases, by promoting the combination of oxygen and carbon. Thirdly, it promotes the chemical union of the particles of fluxes.

The highest heat obtained from the combustion of fuel and the application of hot air, which results in advantage, has been found to be about 500° , or, the melting point of lead. This number, of course, varies according to the kind of fuel employed. A higher heat

will be advantageous if we burn anthracite, and a far lower temperature, if we burn charcoal. If we do not need a high temperature for a given operation, we may economize fuel by spreading the heat over a large surface.

Hot air effects a saving of fuel in proportion as its temperature is the complement of that in the furnace. In nearly every instance of combustion, unburnt air passes through the fuel. The lower the temperature of combustion, the greater the quantity of air which will pass uncombined; that is to say, the heat of the blast or of the nourishing air, which adds directly to the heat of combustion, will be the more apparent, the lower the heat in the furnace.

From these considerations, we may conclude that, where the highest possible temperature is desirable, the application of hot air in combustion is indispensable. But there is a limit to this application; and the air suitable for one kind of fuel may be too hot or too cold for another kind. There is no direct saving of fuel in cases in which the air is to be heated by separate fuel, but only in cases where it can be heated by the waste heat of the furnace itself. The percentage of fuel saved, in the latter case, is equal to the temperature applied to it. It thus follows that, in a furnace heated to 4000° , to which air of 400° is applied, ten per cent. of fuel will be saved; but if the temperature in the furnace is only 2000° , and that of the alimentary air 400° , a saving of 20 per cent. will be realized. This, however, applies only to a combustion which is imperfect, and occasioned by a too liberal supply of air. Where the combustion is smothered, the application of hot blast is disadvantageous; as far, at least, as economy of fuel is concerned, no benefit results from it.

If we wish to work to the greatest advantage with respect to economizing fuel in a blast furnace, we should be careful that the temperature is highest at the tuyeres. Where quality alone is sought for, the heat should be highest above the tuyeres; in this case, the iron will be cooled, and its impurities oxidized, before it settles down

into the crucible. A gradual increase of heat from the top of a blast furnace down to the tuyeres is the object at which we should aim ; and this can be realized by producing, with a certain degree of blast, the highest heat exactly at the tuyere.

Another equally important advantage of hot blast is its mechanical influence upon cinder. The particles of matter which enter into the composition of cinder will be exposed by a high heat, and their affinity for each other increased ; the consequence is, a greater fusibility of the cinder and a saving of limestone. Cinder soon cools, particularly if it is of a silicious nature ; the blast of a furnace, always working more or less upon it, chills it ; in this state, the particles of melted iron will not pass through it ; hence, it will flow slowly over the dam. Hot air keeps it in its highest state of fluidity ; by that means the descent of the iron and the removal of the cinder are promoted. But that which is beneficial to the cinder is very injurious to the iron ; that which makes the cinder more liquid, and imparts to it a more homogeneous texture, causes the impurities to unite more strongly with the iron. This is another instance in which we cannot increase the temperature of hot blast beyond given limits. Unless the blast has been too hot, the combination of impurities and iron can be, in a great measure, dissolved in the puddling furnace ; but not so well in the forge fire.

The advantages arising from hot blast and cinder have brought into use certain refractory ores and fuel, which, before their application, were regarded as comparatively worthless. There is no material, however small the amount of iron it may contain, or in whatever form or combination it may exist, which cannot be revived by a judicious application of hot blast. If the forges could work any quality of pig iron to advantage, the blast furnace might be profitably employed upon cheap productions. By applying hot blast, we are enabled to revive iron from the poorest kind of silicious and aluminous ores, to reduce the protoxide in the silicates, and to revive iron from forge cinders. If the quality of the

product would satisfy the forge-man, the application of hot blast would probable reduce the price of pig iron, in the anthracite and bituminous coal regions, to a considerable extent.

It will doubtless be as appropriate in this as in any other place to make a few remarks relative to the causes of bad iron, resulting either from hot blast and imperfectly prepared ores, or from forge cinder and the native silicates. It is a law of chemistry that matter can be dissolved, under favorable circumstances, in a solvent, which under ordinary conditions, would not affect it. Silix, if in chemical union with any substance, such as oxide of iron, can be dissolved by hydrochloric acid under any condition; while silix in an uncombined state is not acted upon by it. Silix, dissolved in potash or soda, and precipitated from that solution by an acid, is soluble in water; but if the precipitated silix is dried and heated, it is insoluble in any menstruum whatever. This behavior of the silix is, in a greater or less degree, the same as that of most other substances. To investigate the cause of this difference of solubility in matter of the same constitution, does not belong to our department. It is sufficient to know the fact. We shall make use of it, to explain the cause of the behavior of iron ores, with respect to the quality of the iron revived. The object of preparing or roasting iron ore is simply this: to expel from it fugitive foreign matter. Roasting opens the ore, and effects a more thorough separation of the oxide of iron from the foreign matter. It is the latter object alone which concerns us at present. No foreign matter interferes so much with our operations as silix; few other substances interrupt our business. Silix, is a strong acid, and in consequence, probably, of some unknown specific quality, has a remarkably strong affinity for the protoxide of iron. It is composed of oxygen and an unknown, at least not well known, element, silicon. This element has a very strong affinity for oxygen; one atom of silicon combines with three atoms of oxygen, or very nearly fifty parts by weight of the one with fifty parts of the other. From iron ores—in

which an intimate connection exists between the silix and the oxide of iron—the iron cannot well be revived, unless a portion of silicon is also revived. This will appear the more reasonable, when we reflect that silicon has as strong an affinity for the metallic iron as silix has for the oxides of iron. In manufacturing steel, every effort is made to purify the iron ; and yet the best steel always contains silicon. The more intimate the connection between the oxide and the silix in the ore, the greater will be the amount of silicon which the revived iron will contain. The present case is similar to those in which a silicate, or any iron ore, is dissolved in hydrochloric acid. Here, the silix parts more readily with oxygen than with iron. There would be very little prospect of separating iron from silicon, had not iron a great affinity for carbon. Open, well-roasted ores absorb more carbon than close ores ; but forge cinders or silicates absorb none at all. The first make gray iron, which, notwithstanding the large amount of silicon they often contain, can be worked to advantage. The latter always produce hard, cold-short iron, and they generally contain less silix than the first ores. Carbon, if in mechanical admixture, as in gray pig iron, keeps the iron porous ; oxygen will have access to the interior ; and as silicon has, at a low temperature, a greater affinity for oxygen than it has for iron or carbon, it will oxidize before either of the latter. Upon this hypothesis, we can explain the improvement of pig iron by means of cold water. Steam may find access to the interior of the iron, if the latter is suddenly chilled and crystallized. Silix has little affinity for carbon, so has silicon ; but the latter has so great an affinity for oxygen, that it can be oxidized only to a certain extent, if in a body : the resulting silix covers the silicon, and prevents its further oxidation. The heat produced by oxidation, and the cohesion of the silix, are very great. Carbon does not combine with oxygen at a low temperature. If, therefore, silicon is contained in cold gray, or white iron, and if, in this divided state, it is oxidized, it will not cause the temperature to be raised sufficiently high to burn the carbon, and the pig iron or metal may retain all its carbon,

though the silicon will be oxidized to silex; the latter is of no injury whatever to iron. But, if iron, containing silicon and carbon, is heated so far that its carbon will unite with oxygen, and is then exposed to a liberal access of air—whether in the blast furnace, the finery, charcoal forge, or puddling furnace—it will lose its carbon, it will be white. Here the high temperature is the cause of the combustion of carbon. The burning of the silex will, as a matter of course, be the cause of the conversion of a portion of iron into protoxide, with which it will combine; this protoxide is, in turn, reduced to metallic iron by the carbon. Such a process will always take place in large or small particles of melting iron. If a drop of such iron is exposed to oxygen, the latter will oxidize its surface, and the result will be silex, iron, and carbon. But in this heat, carbon has a greater affinity for oxygen than iron; and the oxide of iron, which may have been formed, is reduced by the carbon from the interior of the drop. In this way, the pig iron is deprived of its carbon, its cohesion increased, and its fusibility diminished. If the amount of silicon is disproportionate to that of carbon, the iron is almost beyond improvement, for that heat which will melt it will oxidize it, and transform nearly all, or a part, of it into a rich silicate, without improving the iron which remains, and which may be yielded from such impure silicious metal. Hot blast is, in this case, more injurious than cold blast, for it increases the temperature, and hence, the affinity of carbon for oxygen; but it diminishes the affinity of iron and silicon for oxygen, and increases the affinity of the one for the other.

Hot blast has been applied to charcoal forges, and is still so applied; but experience clearly shows that it injures the quality of the iron manufactured. Hence, it offers no possible advantages, for what is gained in quantity is lost in quality. Charcoal forges are valuable, in our country, as a means of producing quality. If that object is compromised, which is surely the case where hot blast is employed, charcoal iron will be brought to a level with puddled iron. This would be

the surest method of making charcoal forges unprofitable. In the Catalan forge, hot blast may be employed advantageously in the melting down of the ore or cinder; but in the breaking up or blooming, cold blast should be employed.

Hot air is of but little advantage in puddling and reheating furnaces, or sheet iron-ovens, where bituminous fuel, such as wood, peat, or bituminous stonecoal, is used. If we burn anthracite in these furnaces, we may realize a moderate gain by hot air, provided the air can be heated by waste heat. This remark may be particularly applied to the reheating furnace, where large piles of iron are to be reheated; for free oxygen is generally contained in the flame of this furnace even in the highest heat. This oxygen, in some measure, works destructively on the iron to be reheated. Its amount will be greater in an anthracite reheating furnace than in any other; still, it may be reduced by the employment of hot air.

At the blast furnace, economy of fuel is an important object; not so much because fuel is valuable in itself, but because wages are high; the handling of fuel, as well as the keeping of a fire, requires labor. For these reasons, air is generally heated at the top of the furnace. Coke furnaces may be considered, with the exception of a few anthracite furnaces, the only ones at which the blast is heated by separate fuel, and where extra labor is required. The top flame of the blast furnace contains far more heat than any air apparatus requires. The air stove should be so constructed as to secure durability and simplicity. The flame may be conducted directly from the top to the stove; or the gas may be tapped below the top, and conducted in pipes or channels to the stove, just as we choose; either method is good, and by either method we may obtain as much heat as we require. Where the steam which drives the blast machine is generated at the top of the furnace, as is generally the case, it is advisable to place the air-heating stove at the end of the steam boilers; for there is sufficient heat left, after the flame has passed under

the steam boilers, to heat the blast to any degree which may be considered profitable. What makes this arrangement, common at the anthracite furnaces, more profitable, is the fact that the gas, by the time it passes the steam boilers, is, in some measure, cooled, and not sufficiently hot to injure the air-pipes. This result frequently occurs where the apparatus is put directly to the tunnel-head.

The economical advantages arising from the application of hot blast, omitting those cases in which cold blast will not work at all, are immense. The amount of fuel saved, in anthracite and coke furnaces, varies from thirty to sixty per cent. In addition to this, hot blast enables us to obtain nearly twice the quantity of iron within a given time that we should realize by cold blast. These advantages are far more striking with respect to anthracite coal than in relation to coke, or bituminous coal. By using hard charcoal, we can save twenty per cent. of fuel, and augment the product fifty per cent. From soft charcoal we shall derive but little benefit, at least where it is necessary to take the quality of iron into consideration.]

History of the Hot Blast and of Modern Applications and Improvements.

In 1828, a patent was granted Jas. Beaumont Neilson, manager of the gasworks of Glasgow, entitled "Improved Application of Air to produce Heat in Fires, Forges and Furnaces where Bellows, or other Blowing Apparatus, are required." The essential principle of which was to pass the air, or blast intended for the heating or reducing of the iron or ore, through an iron chamber heated to a considerable temperature above the ordinary blast temperature. The reception chamber was to be heated to redness though the beneficial effects were felt at a lower temperature. Neilson's first blast oven or stove was similar to a "wagon head" steam boiler, one being used for each tuyere and about 4 ft. long, 3 ft. high, and 2 ft. wide, set in brick with a fire

underneath. Before this time it was thought that the colder the blast the better the results. This was deduced from the fact that the produce, per furnace, was greater in winter than in summer, so that blasts were passed over water to cool them. But this was followed by unsatisfactory results, inasmuch as the blast took up water, for it was found that the same unequal production of iron in winter and summer took place when the blast was heated to 600° or 800° Fah. and was due to the moisture invisible in summer, yet more extensively present than in winter.

Percy thinks that in order to inject the same amount of oxygen into a furnace in summer as in winter, the blast engine must be driven to a higher rate of speed.

In 1831 raw coal was used instead of coke, and the temperature of the blast raised sufficiently to melt lead and even zinc—and the use of the water tuyeres had become necessary.

The Apparatus.

A large amount of ingenuity has been exercised upon the various modes, material, and sizes of the blast furnace or oven. At first, Neilson used wrought iron, which was found to corrode too rapidly: cast iron was then introduced. At the first he raised the temperature to 200°. In the next and improved plan, which was that of a cast-iron cylinder, bottle shaped at either end, the temperature was raised to 280° Fah.

In the third improvement the hot blast may be said to have commenced. In this improvement Neilson introduced an arrangement of horizontal cast-iron pipes, 18 inches in diameter, and united by flanges. They formed a continuous length of 100 feet, and presented a heating surface of 240 sq. feet. In this he raised the temperature to 600° Fah. sufficient to melt lead.

But the difficulties now began. These arose, first, from unequal expansions and contractions of joints. The leaks occasioned by these expansions and contractions were overcome by cast-iron rings—these broke the pipes.

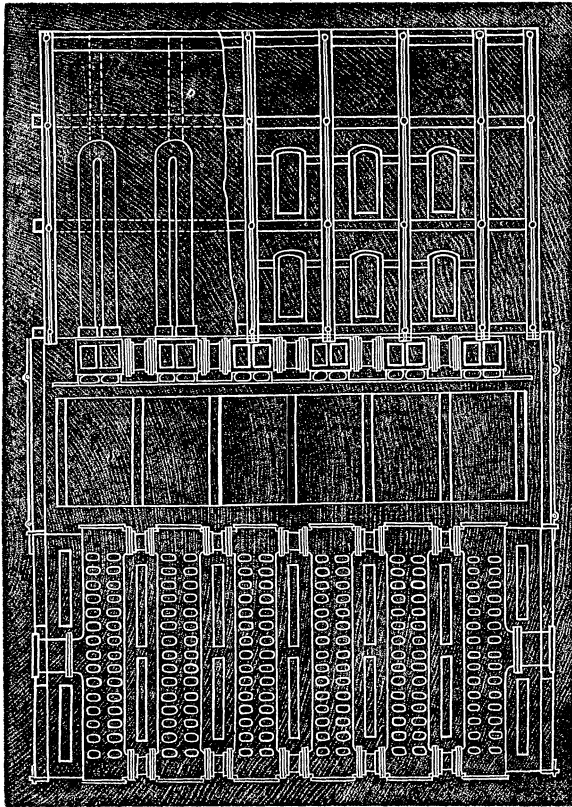
Next came into use, invented by Neilson, "the cast iron tubular oven." This consisted of two cast-iron cylindrical, parallel horizontal mains connected by a series of smaller arching cylindrical pipes with their convexity upward. The ends of these semicircular pipes fitted into sockets in the mains. The fire was made between them in a grate, and the whole inclosed in the semicircular arch of brickwork with a flue chimney. The mains were laid in brick; the sockets under the ends of the arch pipes, only, being left free. This worked better than any previous plan, and upon this all the many modern plans are simply and mainly improvements.

The next difficulty, attendant upon the use of the arched pipes, was, that the convex sides cracked from the expansion and the permanent position of the sockets in the mains. This was remedied by causing the mains to move on iron balls, and it was found that they would move as far as two inches. This suggested the formation of a pyrometer indicating the blast heat by the movement of the mains. Such a pyrometer, consisting of a lever with a very short arm impinging upon the main and a long arm outside the oven, was introduced, which, after the amount of movement for any known temperature was measured, would indicate any lesser, or higher temperature with accuracy. Hitherto, the arch-pipes had been made converging at the ends, but while cracks at the upper part, or convex side, were in a greater degree prevented, they now occurred on the under, or concave side, due to the fact that after the heavy mains were extended, the arched pipes were not sufficiently strong to draw the mains in, and the pipes cracked on the concave side. This was counteracted by abandoning the loose mains and making the sides of the siphon pipes parallel so that the upper part of the arch was rectangular with the angles rounded. These stand well. Of this form there have been several modifications to suit position and size of furnaces. There is one, however, singularly different, to which we may allude in passing. It is an acceptable and efficient blast oven, and is that of the English round oven used at the Russel's

Hall furnaces, near Dudley. The main is circular, of iron, and cast in two semicircular portions. A cross section of the main is trapezoidal, the bottom (which is widest) and the top plates being parallel to each other; the siphons rise from the lower main to an upper and the heated air is thus returned from upper to lower, the furnace gas flame heating the siphons as usual.

The latest and best general forms of the hot-blast oven, in our country, are those in which the pipes are

Fig. 103.

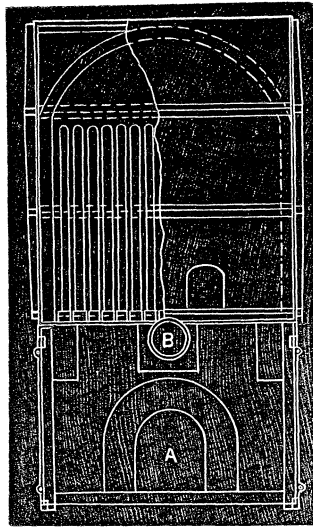


Hot blast, Seranton, Pa. Side elevation and plan.

siphons whose cross-sections are elliptical, as in Fig. 103, in which we have the whole arrangement of an oven

erected last year at Scranton, Pa. The drawings with end Fig. 104, and side elevation and plan, Fig. 103,

Fig. 104.



Hot blast. End elevation.

sufficiently explain themselves, with the exception that Fig. 103 is drawn without a line of distinction between the plan, and the beginning of the elevation, but we need only call attention to this point to prevent any confusion, as the two are drawn with great accuracy to show the relative juxtapositions of all the parts in plan and both elevations.* The entire length is about 29 ft. 7½ in. The pipes are 6 in., measuring through the shorter diameter of the ellipse on the outside, and on the inside 4 in., the iron being 1 in. thick. They are nearly 8 ft. 9 in. above the sleeve, into which they are cemented by the cement spoken of on a previous page. The bed pipes are 14 ft. 6 in., and the division inside makes two chambers of each main, so that the blast passes up the fifteen siphons and down at one time, and thus onward to

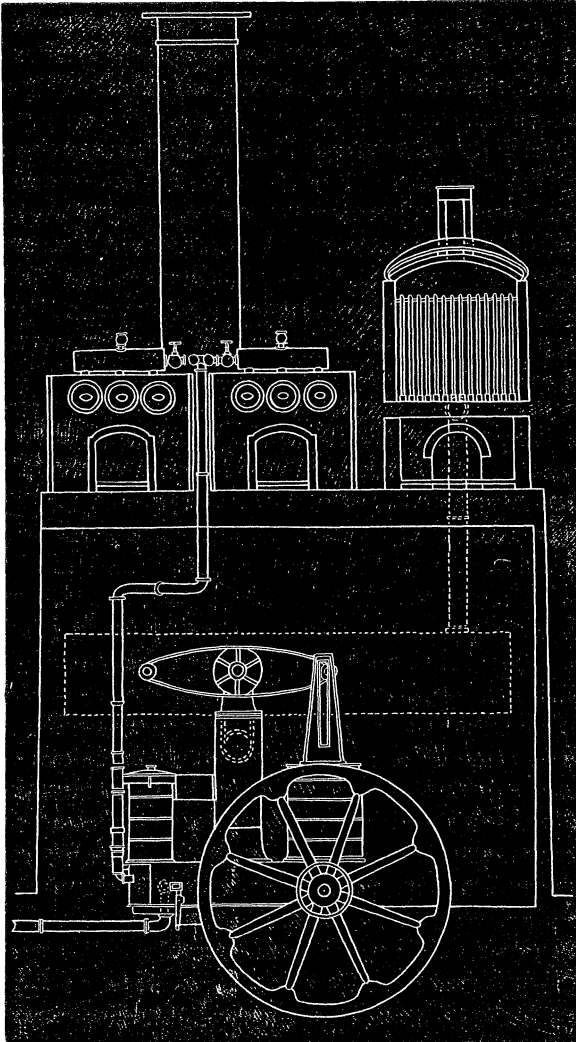
* I am indebted to my pupil, N. J. Bayard, of Georgia, for the preparation of these drawings.

the next fifteen, and so on till delivered at the opposite end where it is received by pipes which have surrounding jackets through their entire lengths, serving the purpose of non-conducting air chambers. This plan, where the pipes must pass through exposed situations, is admirably adapted to preserve the temperature acquired in the oven, and abundantly repays the first expense. The oven doors are fastened by latches, a plan we think not quite so safe as that adopted at the Saucon Iron Works, where the hinge frame is shot out at the bottom, and the doors, therefore, close by gravity, and, upon sudden expansion by explosion of gas, will open immediately affording some relief to the pressure. The closed door A, Fig. 104, in special emergencies, can be opened into the main fire chamber; the hot blast is delivered at B.

A still more complete arrangement is to be seen at the Saucon Iron Works (above referred to), where the blast is so arranged that one-half may be cut off at any time for repairs or for any other purpose, while the other half works on. The whole arrangement for one furnace is so compact that we give the whole cluster of buildings in the following elevation, Fig. 105, of engine, boilers, and blast oven, and smoke stack, indicating the whole order, or plan of the furnace. The column of support for the walking beam of the engine, is put to the purpose of conveying the blast, in part, to the right and upward to the hot-blast oven. The boilers, as indicated, may be used in two triplets, or in one.

It has been supposed, by some ironmasters, that the cylindrical siphon pipe is preferable to the elliptical, and so this form has lately been introduced into this country. The pipes are generally longer, rather less in sectional area than the former type, and perfectly round. No doubt this form is equally good as respects heating power, and perhaps on the whole somewhat better than the elliptical form. A supposed improvement has been introduced in the elevation of the roof of the oven, the object being to afford a larger space for gas, and consequently a large mass of heated air. In some cases this is an improvement, but, with some ores and fuel, so much

Fig. 105.



General Plan Saucon Works, Pa.

heat is disengaged that there is no call for any additional heat, and the larger the walls the more liability to cracking, and to loss of time in repairs. Some improvements lately introduced upon the continent of Europe may be presented, briefly, before closing this part of the

subject. First, the horizontal pipes in serpentine arrangement of Wasseraalfingen employed in Westphalia. The following is a correct copy of the oven as given by Petitgand & Ronna. The tubes are either round or elliptical, and are sustained by irons running into the furnace. The arcs or curved connections are found to be most conveniently arranged, and sufficiently retentive of heat, when placed outside the wall. The ascending flame seems to heat more powerfully than any other flame, and this oven utilizing such a flame, gives great satisfaction in several places on the continent. It had not been introduced into England at the time Messrs.

Fig. 106.

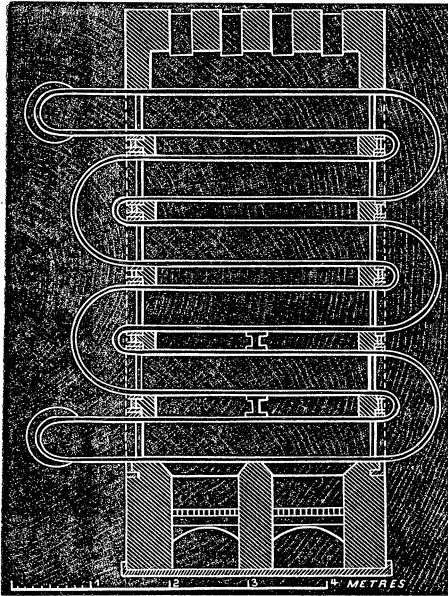
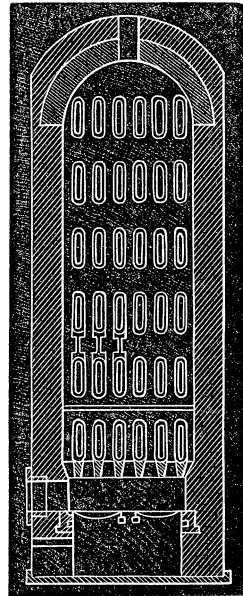


Fig. 107.

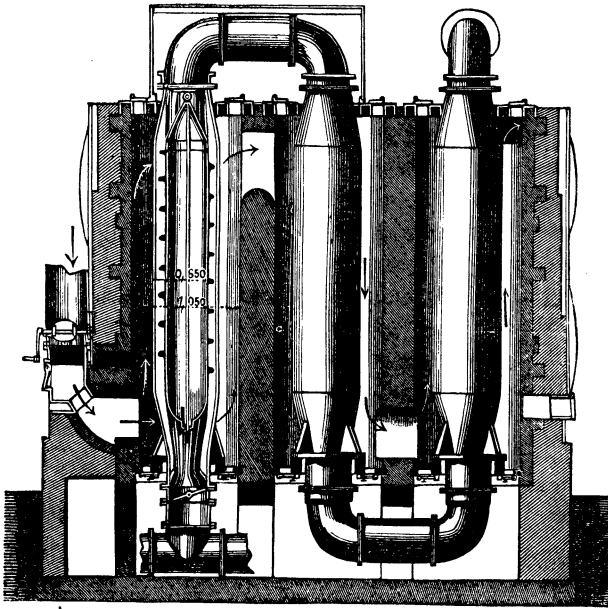


Wasseraalfingen Hot Blast.

Petitgand & Ronna published their Appendix. A still later improvement has been announced as that of Thomas & Laurens. The principle need only be stated with the following representation to render it sufficiently plain without any minute description. The object desired is to throw the blast current into a cylindrical

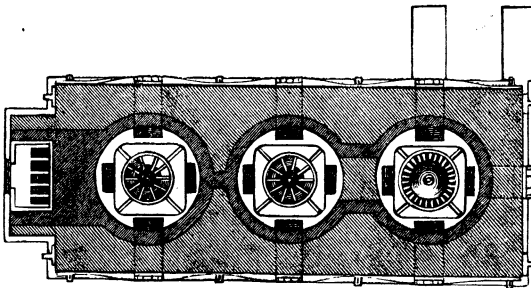
form, and thus expose it to the influence of the heated tube, or cast iron, surrounding this cylindrically formed current. There is a core around which the cast-iron

Fig. 108.



tube, and between this and the core the blast current is forced. The ignited gas surrounds this tube, and the

Fig. 109.



blast is, so to speak, forced up against the heated side in a thin stratum of air. It will be noticed that in Fig.

107 the core pipe is dentated, or spurred. Fig. 108 is a plan section at the base. Fig. 109 the end elevation. Fig. 110 sectional plan of the top. This form has not been reported upon as yet fully tried, but the apprehension is that there will be considerable resistance to the blast, requiring more power, or a greater pressure per inch to force the air through the blast oven. The advantages claimed for it are rapid heating, the requirement of a smaller stove for some degree of heat, and an easy access for cleaning, and therefore greater economy.

Fig. 110.

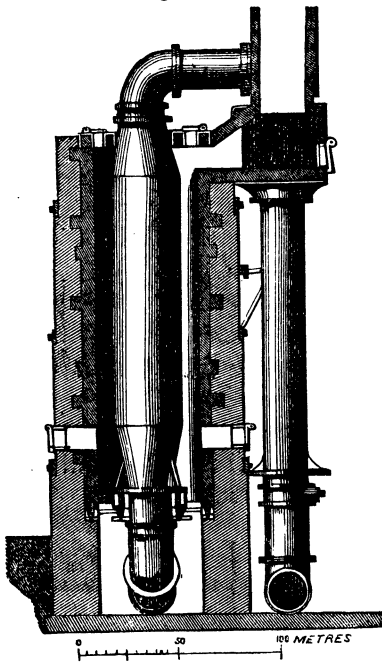
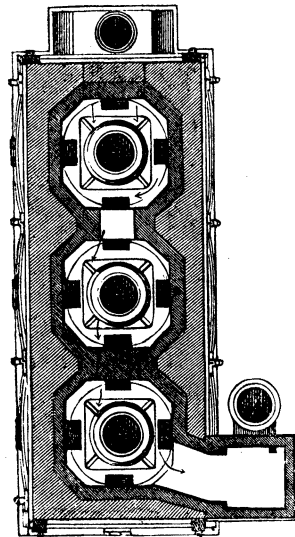


Fig. 111.

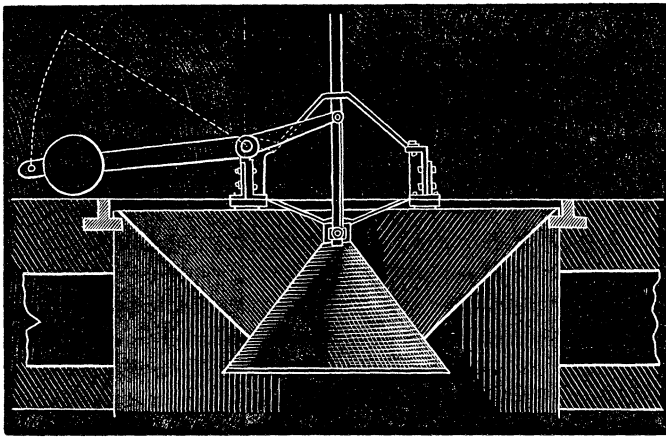


After all, it is probable that the plan, suggested, as adopted in the American elliptical and simple siphons, very close and parallel in the several bed pipes with ample room in the oven, is as near, as need be, the most economical and most convenient, where the heat is not made excessive.

Some furnaces have lately adopted the method of

placing the blast oven upon the level of the hearth of furnace, and not, as formerly, upon a level with the tunnel head. This plan has been adopted for years in many furnaces in this country and abroad. At Port Henry, Lake Champlain, the gases are cut off entirely, and no light nor gas is seen excepting from the tunnel head. There is, as in the following cut, Fig. 112, a "cone and cup," plan of shutting down the gas and forcing all through a pipe descending to the blast oven upon the ground.

Fig. 112.



In some furnaces such a treatment would probably be followed by the production of forge iron. The iron formed at Port Henry is mottled, or forge iron intended for the rolling mill, but this is attributed to the compact nature of the magnetic ore. Where open foundry iron is desired, it is doubtful, especially with certain peculiar grades of ore, that a high order of iron would result upon such a treatment. So far, however, as distributing the charges is concerned, the plan, in some degree, is a good one, and this method of mixing and distributing the charges is adopted in many furnaces both in Britain and upon the continent. In America, a method to effect the last mentioned object is adopted, which works equally well when the fillers are honest and careful

men. It is the plan of surrounding the tunnel head with a wall perforated with a certain number of gates or doors, and requiring the men to fill through these doors, using them alternately. Perhaps a combination of the two plans might be more effectual than either by itself; but a ground oven may be used with an open furnace.

When the blast oven, placed upon the ground, is heated by the waste gas from the tunnel head, a large and high smoke stack is needed to draw the gas down from the tunnel head to the ground, for there must be a large resistance to this downward course of the rarified gases. In some locations, or positions, there is no adequate benefit resulting from the adoption of this method.

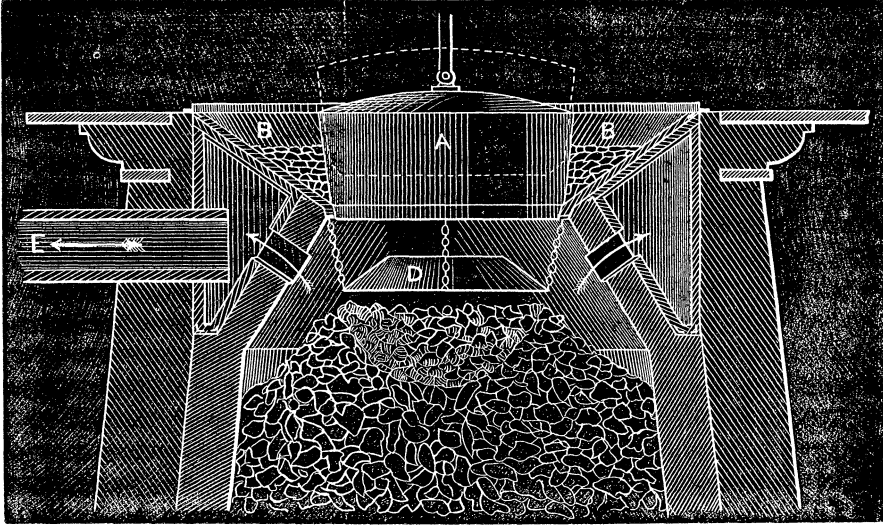
In regard to the openness of the tunnel head there are various opinions reconciled by consulting the ores fluxed and the fluxes used, for methods vary from the above-mentioned plan, from absolute stoppage to entire opening and escape of all the gas from the tunnel head, but the most open foundry iron, and the freest from injurious substances, is made where the tunnel head-gases escape most freely. As we have said, this freedom of escape may be induced even where the tunnel head is somewhat covered, and the gases somewhat condensed, by leading the gas off downward and again upward by a powerful draught of air caused by a large and very high smoke-stack rapidly drawing the air off from the ground blast oven, but it must needs be erected with great care to insure the result desired, or else the very furnaces which made good foundry iron will certainly lose their power to make so fair a sample of iron with the same ease, and upon the same conditions, as formerly; at least until the new order of things is fully understood and the evils provided against.

As for the methods of retaining, diverting and utilizing the waste gas, as adopted of late, the following representations will afford an idea of inventions which give satisfaction, and, at the same time, exhibit the efforts made at the present day, in Europe, to meet the wants in this direction:—

Fig. 112 shows a method introduced by Cochrane at

Ormsby, England, which is a modification of that "cup and cone" system introduced into England and used at

Fig. 113



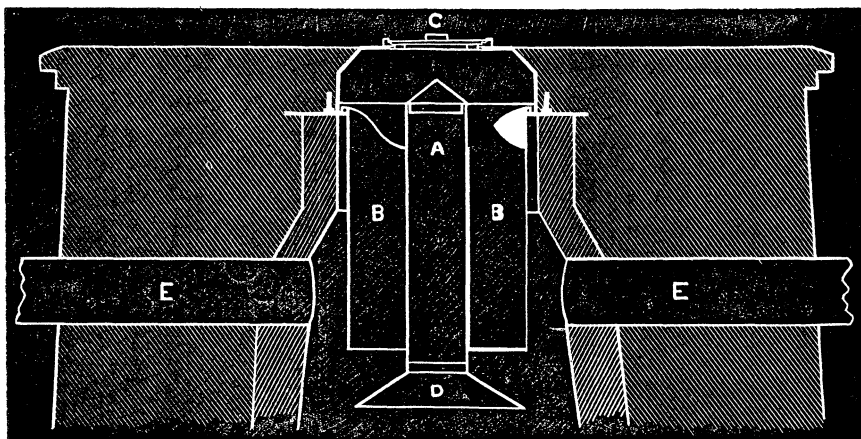
Cochrane's distributor.

the furnace at Port Henry. It comprises a truncated cone, A, of wrought iron; B B, a circular gallery, or trough of cast iron into which the mixed ores are thrown; A being raised by a windlass to the position indicated at the dotted line, the ore falls against D and is distributed. This plan is spoken of in the highest terms as producing foundry iron where the ordinary method of throwing in the charges was followed by the production of white iron. The arrows indicate the course of the gas into the circular chamber and out through E.

Fig. 114 is the representation of a covering and a charge distributor which is, in some respects, more complete in its power of distributing the ore. It is an invention of M. Prenat, director of works at Givors, 13 miles south of Lyons, France. It is highly spoken of. A is a stationary cylinder terminated with a cone, which is sustained by four arms of wrought iron. B B is the cylinder protecting the gas flues at its lower end; if

necessary to close the furnace it is done at C. by a cast-iron door, at which place the charges are delivered and

Fig. 114



Prenat's distributor.

scattered as they strike A and again distributed against the walls of the furnace at D. It is plain that A D must be better sustained than is represented in this engraving, which is (letters excepted) on the authority of MM. Petitgand and Ronna; this strengthening might be accomplished by introducing into the edge of D four wrought-iron yokes with bars extending to, and united with, plates in the bottom of the gas flues E E. The method of charging is undoubtedly good.

When the furnace throats are large and cars are to be used, another plan has been suggested by Escalle and used to extract the gas from the central part of the furnace, allowing building the furnace walls up solid. The gas is carried off by flues; the cone, called the distributing cone, moves downward by its own weight, in part counterpoised by weights P P (Fig. 115), on long arms or levers, sustained by the arbors at H, or on that line. The wagons, or barrows, open underneath at F F (Fig. 116), and discharge into the cavity at A, and against the cone B B, which descends vertically around the gas pipe C, guided by slide rods L L; J J being the suspension connections

Fig. 117.

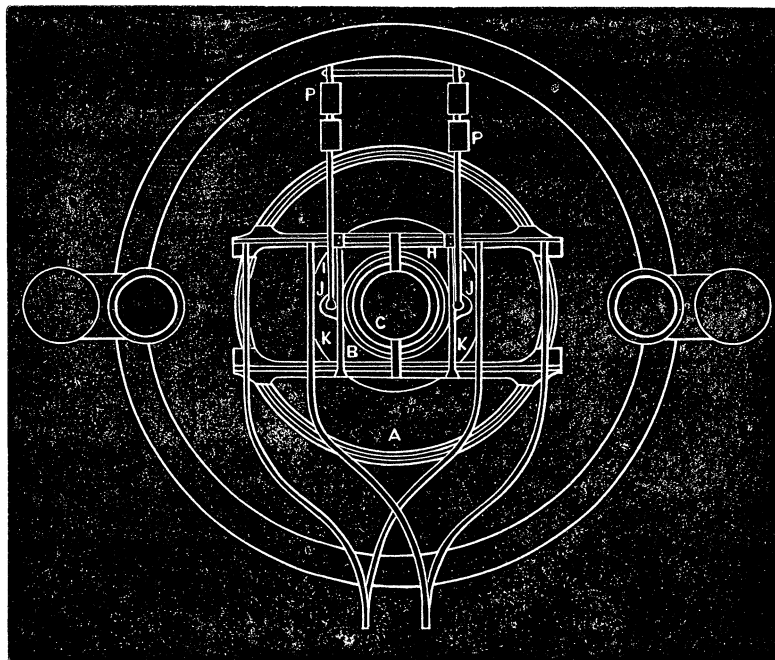
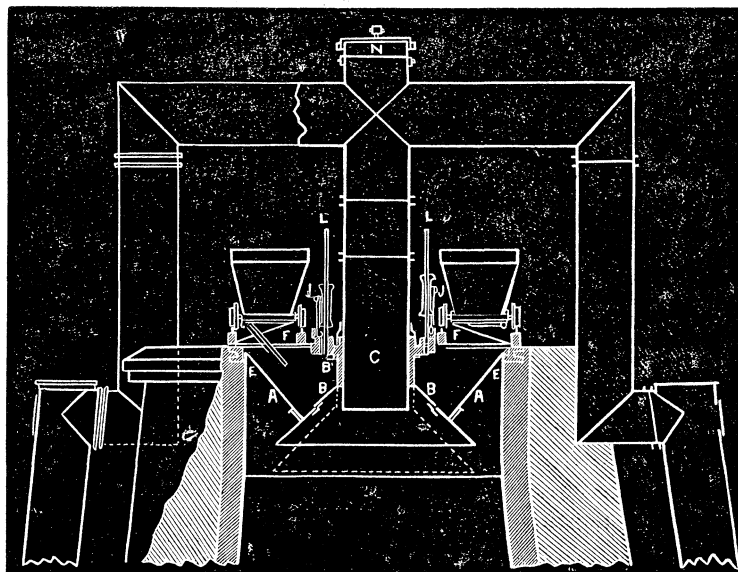


Fig. 116.



Escalle's method.

of the long levers. E E is the cylindrical casing for the support of A A. N is the valve for escape gas when such escape is needed. The rest sufficiently represent the principle and object.

Player's Blast Oven.—A modification in the use of the waste gases from the tunnel head is seen in the operation of this oven. We adopt the following description, sent us by Mr. Henderson, slightly altering some parts which make it more in accordance with our own personal knowledge of its action, of which we shall speak hereafter.

The practice of Neilson of Scotland and that of all others, subsequently, until Mr. Player's invention, was to consume fuel, or ignited gases, in contact with iron pipes through which the blast circulates; by this means they were unable to get over 600° without destruction to the pipes, owing to the irregular manner of heating the blast, which was due, in part, to the arrangement of the apparatus, and the mode of using the gases. It being found impossible to consume entirely the gases among the pipes, so as to make the chemical change caused by perfect combustion of the carbonic oxide into carbonic acid among the pipes, owing to the intense heat thereby generated, which would soften or melt down the pipes; and the pipe chamber being filled with comparatively cold surfaces, could not readily get the required heat to insure perfect combustion, which is obtained where the gases are consumed in a chamber where the temperature is constantly that of welding heat of wrought iron, as is the case with Player's Patent Stove.

This stove is shown in the annexed figures; 117 being plan at lowest point, 118 at a higher level. The lower chamber is composed of fire-bricks, and has numerous openings in the top of the arch; the gases from the blast furnace are introduced therein, and inflamed with an admixture of air. The reddish-purple fumes of this gas ascend through the slats in the upper part of the combustion chamber, into the chamber above Fig. 119 containing the cast-iron pipes through which

Fig. 117.

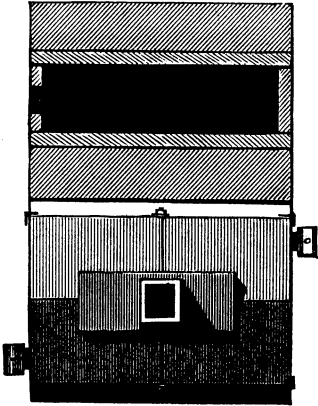
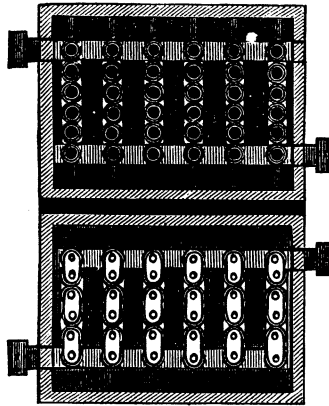
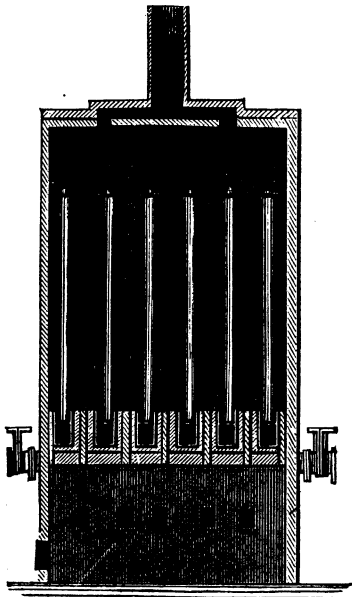


Fig. 118.



the air passes and is heated. The upper or pipe chamber is pervaded at all times, with a red hot atmosphere

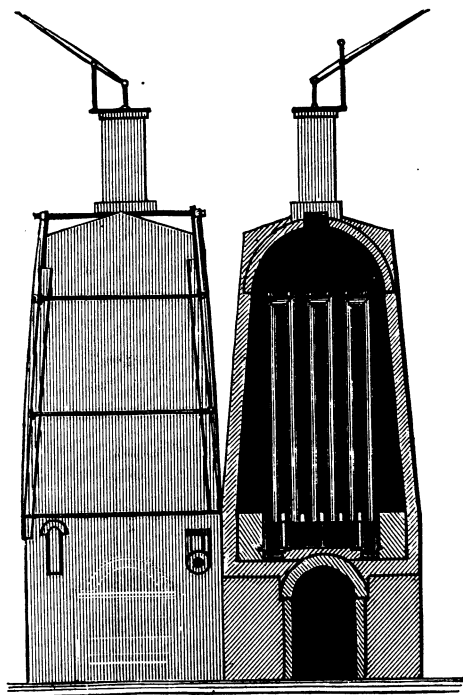
Fig. 119.



which acts on all parts of the pipes alike, and has the appearance of a dim red heat—no flame is visible

among the pipes; the pipes are maintained uniformly throughout the stove at a blood red heat in daylight, or from 1000° to about 1200° Fah. The air enters one of the ends of the horizontal mains, and ascends and descends each of the triplets of vertical pipes three times. There are stops in the cross troughs, Fig. 120, which

Fig. 120.



force the air up and down each pipe, thus insuring the passage of the air over all the heating surface of the stove; about twice the area to a pipe is given in a stove to that usual in the common kind. The usual size of Player's stove is 18 pipes, as in the figures, of a siphon, or inverted U form, containing about 1000 square feet of heating surface, which will heat 2300 cubic feet of air per minute, to 1200° Fah.

There are some advantages pertaining to stoves built

and worked under Player's patent, which are not to be obtained by any other kind, such as much less destruction of pipes; indeed it is claimed that there are no repairs of any kind, whereas in a common oven the whole affair is often totally destroyed in one or two years, and there is almost a constant renewal of the blast pipes; a greater uniformity of temperature of blast is also obtained, some parties report variation not over 20° a day, whereas the temperature of the common oven is constantly varying, affecting the working of the furnace, which can never, with the ordinary arrangement, be expected to make any desired quality. So far as dependent upon uniformity of blast heat, it is altogether a matter of chance. A high uniform temperature insures the best results as to quality, quantity, and economy of production.

We have seen this hot blast in full operation at Bethlehem, Pa., at the new Northampton furnace, or No. 3. The gas is brought down to the ground by a heavy sheet-iron pipe, brick-lined inside; it then passes first into the foundation between the two ovens of 60 fourteen feet pipes, and thence to three nests of boilers and then back to a 110 feet smoke-stack. The ovens have no gas chimneys, as represented in our cut. The gas is conducted and burned with atmospheric air, as above described. The entire arrangement of siphon and bed pipes is inclosed in the brick chambers.

The stove gives entire satisfaction, the main points appearing to be as given above, namely, great heat with less pipes, longer endurance of pipes because of the manner of burning the gases just before touching the pipes, uniformity of heat. It appeared to us that the extreme heat claimed for this stove was not attained, but as this may have been due to stoppage and to defect of the pyrometer, which did not reach 800° during one afternoon, we could not form a fair opinion. But if it should prove that, with identically the same heating surface exposed to the flame in the common way and also in the way of the Player's oven, the latter should give less heat, it would afford us no surprise that a pipe

out of a flame should not be quite so hot as one *in a flame*. Nevertheless, as we are not yet prepared to advocate the entire economy, all things taken into consideration, of the extremes of temperature adopted, we are of the opinion that the method of burning the gases upon Player's plan, is the most saving of the oven and pipes of any other invented, and it is perhaps more uniform, and as a whole a decided improvement.

Mr. Horton, of Rochester, has somewhat improved upon the plan at Bethlehem, by utilizing the gases more effectually, by a series of jets rather more readily controlled than in the plans we have hitherto spoken of. Certainly the working of the furnace seems to advocate the use of this oven and his method of utilizing the gases. It is thought that should this furnace, which is only 14 feet bosh, 50 feet high, 5 tuyeres, be burdened to run forge iron, it would make from 35 to 38 tons of metal per day, with use of $1\frac{1}{4}$ tons coal only to make 1 ton iron. But what has actually been accomplished (see previous page) is sufficient. The gas is utilized in this furnace so completely that there is sufficient to run 6 boilers 60 feet long (with other boilers under 45 feet each), and three large hot blast stoves which heat up, as Mr. Horton thinks from 900° to 1200° Fah. In these estimates of iron made it is necessary to know that this furnace has carried 3000 lbs. ore, on 2000 lbs. coal, or in other words, smelted $1\frac{1}{2}$ lbs. ore with 1 lb. coal—proving clearly, with what we already know, the richness of the ore.

Upon the former method of using the waste gases, Mr. Thomas, of Hokendauqua, has made some improvement in the course of gases as they impinge upon the pipes, and in the form of the cross section of the pipes, as we have elsewhere intimated, and in his stoves the subject of temperature arrived at, brings no doubt to the mind of any one of an evening, who looks upon low red hot pipes conveying hot blast to the tuyeres, a circumstance which has frequently taken place at the Thomas Works.

As to the utility of high temperatures opinions vary, some finding 600° Fah. quite sufficient for all purposes and in this opinion the vast majority of judges agree. Some have, in this country, raised it to 700° and others to nearly 1000° or higher, as we have just seen. A low red heat in iron would indicate about 1000° Fah., or 1100° according to some authorities.

It is a subject of doubt whether those furnaces claiming certain high degrees of temperature ever actually accomplish the heights claimed. The great tendency is to overestimate degrees. After all, the more important point is *uniformity* of temperature—this proves to be more valuable than high temperatures, especially, after about 600° is reached. Much, however, depends upon the fusibility of materials used and of substances in the ore and limestone. All ores and limestones containing much alumina and silicates of alumina must have more heat—others will do as well with less.

Pyrometers of various kinds have been used, but we are not aware of any which answer all the demands, which are mainly, 1st, simplicity of construction; 2d, constancy of operation; 3d, ability to stand incessant temperature up to red heat without melting. The 1st and 3d conditions have been fulfilled, but all pyrometers depending upon uniformity of expansion and contraction of metal seem sooner or later to lose their accuracy and indicate less than the true temperature, and, therefore, fail on the second demand. The instrument, arranged with a finely mixed feldspar clay—well baked—encased and graduated, is perhaps the most constant. But we are not acquainted with any instrument sufficiently constant and trustworthy, although there are such recommended by various makers.

Mr. James Lanagan, of the St. Clair Iron Works, Pottsville, Pa., has been using Gauntlett's Pyrometer, and is of opinion that it comes nearest to the object desired in such an instrument. It was introduced into the Cleveland Iron Works, and some notices of its working, which we have seen, speak highly of it. An interesting

point in this pyrometer is indicated in the following extract:—

This instrument is a combination of the pyrometer with clockwork whereby the temperature of the hot blast from a heating oven, or of hot air in a stove, or of gases in a steam boiler flue, is continuously written down on a slip of paper by the instrument itself.

Extract from Stockton and Hurtlepool Mercury.

A series of daily diagrams exhibits the temperature of the air of the "hot blast," as it enters the iron smelting furnaces. This instrument, simple in construction, metes off the temperature on a cylindrical roll of paper, which serves as a record for twenty-four hours. Mr. Gauntlett, the inventor, has recently secured a patent for this ingenious apparatus, which may be thus described. The cylindrical roll, we have above referred to, is ruled in lines, which describes the circumference of the roll, corresponding to the degrees of Fahrenheit's thermometer, extending to 1000° of heat. At right angles with these, are a series of vertical red lines which represent the consecutive hours of the day and night. Upon these papers, which are fixed in connection with the time-piece, and also in communication with the heated atmosphere, the temperature of which it is desired to register, the time and heat are continuously recorded by means of a small common lead pencil. The diagram exhibited consists of seven slips for each of the three furnaces, and exhibit the temperature of the heated air therein employed during every hour of the week; and it is somewhat interesting to observe the sinuous course which the line pursues, rising and falling, (corresponding, no doubt, with the manner in which the fireman has attended to his duty). Along the line, at pretty nearly equal distances, we observe a series of very sudden depressions. The line appears to fall down precipitately, and, after making a slight progression, to mount up and advance as before. These eccentric divergencies, mark, we are informed, the period when the furnaces were "tapped," during which the heated air is shut off, and ceases to affect the instrument. The invention, we understand, has been highly appreciated by several of the iron masters of this district; and, we have some pleasure in noticing it, as one of the native productions emanating from the new and rising iron districts of Cleveland.

A member of the Cleveland (England) Institution of Engineers gives a very good list of the pyrometers generally adopted in England in the following words:—

First. A stick of lead, which, melting at 612° Fahr., is at best but an approximation in high temperatures, and can only be tried at the tuyere.

Second. A stick of zinc, which, melting at 750° Fahr., is also no guide to a maximum temperature ranging 200° above the melting point of this metal. This can only be tried at the tuyeres.

Third. Gauntlett's patent pyrometer, depending for its action on the expansion and contraction of a straight bar of copper. This pyrometer is of use up to 850° , hardly to 900° . Above this temperature it fails, as the copper rod does not contract, after high temperatures, to the same starting point. The advantage of this pyrometer is said to be that it is a constant indicator to the first temperature mentioned above.

Fourth. Krauss & Co.'s patent pyrometer, depending for its action on the expansion of a spring, one foot in length and a quarter of an inch thick, of the metal palladium. This being made abroad, and the springs being only procurable at Berlin, a great scarcity of these instruments prevails. This pyrometer is not constant; it works up to 1200° , but we have found them falling as low as 1000° from unequal action, broken springs, etc. It cannot be trusted over 1000° , but is a constant indicator.

Fifth. Siemen's patent pyrometer. This instrument is constructed on the supposition that if an imperial pint of water be placed in a copper vessel, protected from radiation, and a ball of copper or iron, one-fiftieth part in bulk of the pint of water, be immersed in the hot blast at a tuyere, and when heated to the temperature of the blast be at once plunged in the water above mentioned, for every degree that the pint of water is raised in temperature the heat of the blast must be 50° + the initial temperature of the water. Thus, if the temperature of the water be 60° , and be raised 20° by a heating medium one-fiftieth of its bulk, the temperature of the blast must have been $1000 + 60 = 1060^{\circ}$.

The unhandiness of this plan is seen at once, for it is not so easy to measure exactly the imperial pint of water; and if the water be not exactly fifty times the bulk of the ball the ratio is destroyed. Again, this operation can only be employed at the tuyere of a furnace, and while the mean may be 1000° , one stove may be at a low temperature while others may be melting down.

Hence, the need of a regular indicator for hot blast, whether by night or day, will be seen at once, and it is hoped that scientific men will take the matter into consideration, as cast-iron stoves will not stand a higher temperature of blast than 1200° without burning down in a short time; and as in iron smelting

the saving in fuel is in proportion to the temperature of the blast, it will be seen that a perfectly trustworthy pyrometer will be a great boon to the iron trade generally.

In modification of the above remarks, we would say that after repeated experiments upon brass and copper, we are inclined to the opinion that no metal exposed either directly to the heat, or when coated with fire-clay, will allow of expansion and contraction beyond a limited number of times, without losing its contractile power. As for copper and other metals, a great benefit would ensue upon adopting a plan whereby the hot blast might be turned upon the pyrometer only when the heat of the blast is to be measured. Pyrometers which are good indicators at first, would remain so for a far longer time were it not for the unnecessary exposure of the instrument to the full heat continuously. We think, therefore, that the practical hints suggested by the failure of pyrometers should lead furnace operators to some method of shielding the pyrometer from the continuous action of the blast.

Gauntlett's pyrometer, it is said, has been used much more extensively for blast furnaces in England than any other. His original instrument was made in this way: The outside tube was of brass about one inch in diameter; an iron rod was placed inside this tube, and secured to the lower end of it; the upper end of the brass tube was screwed into a circular case carrying the multiplying gear which gives motion to the pointer; the brass stem of the instrument is inserted in the hot blast, and the difference in the expansion between the brass tube and rod gives the motion to the pointer. The instruments made in America are similar, except that the tube is shorter—about one foot long. These brass tube instruments answer well for low temperatures, say under 600°. Above that, and about 1000° and 1200°, they rapidly deteriorate. For the higher temperatures now used Mr. Gauntlett makes an instrument with a wrought-iron stem inclosing a porcelain tube. For high temperatures, up to 1500°, these are said to be the best in the market.

The comparative economy of the hot and cold blast has been the subject of dispute, especially by Truran. He supposed it to be not one-fourth of what was attributed to it. The reason given was that from 24 to 30 hours after the arrest of the hot blast and the introduction of the cold blast—"the furnace makes more iron with the original burden and no deterioration is to be seen in the quality of the iron." But after that period the rate of descent is checked and the quality changes, in from 36 to 40 hours the furnace will have returned to its original rate of working, and the quality of the iron be deteriorated to white; from 48 to 60 hours the furnace works as it would with the cold blast. While the make is 105 tons average a week with the hot blast, the immediate substitution of cold blast has temporarily increased the yield to 115 or 116, but when the additional coal is added to make amends for loss of heat in the hot blast, then the yield was 96.

It seems that the explanation of this phenomenon is as follows: When the fires are withdrawn from the heating stoves of a blast furnace, for the purpose of using the cold blast, more air must pass into the furnace in a given time as its temperature falls and bulk decreases and the furnace must "drive faster" until the fresh charges reach the bottom. At the time the hot blast fires were withdrawn, the excessive heat upon the furnace would allow the charge to be driven, but not when the hot blast burden came down to be treated with a cold blast; then, unless the burden be lighter, the reducing iron would be acted upon by the oxygen and the blast and be converted into a "black scouring cinder." Stoves may be let out for a time for repairs without any injury, but if they remain thus for too long a time the effect is injurious.

That the heat is greatly increased in the hot blast is evident from several facts: the water tuyeres are necessary as other tuyeres would soon be burned away—again the iron seen through the eye of the tuyere in the hot blast is intensely brighter than in the cold blast. Again, the formation of long tubes from the cinder forming around the end of the tuyere and called "noses" is only

exceptional in hot blast, whereas in the cold blast it has occurred that the nose has formed away from the tuyere up against the opposite side of the hearth and been returned so that the air has impinged upon the wall of the furnace with such power as to injure the wall, and make it necessary to stop the charges and blow the furnace out.

The blast has been heated considerably above redness at one English furnace, on a plan invented by Mr. Cowper, with coke, and the saving supposed to be 5 cwt. of coke per ton of iron, &c., an increased make of more than one-third. But Percy says that it has been tried by others without any beneficial results.

CHAPTER VIII.

NATURE OF THE GASES—AND THEIR ECONOMIES.

FROM numerous experiments by Bunsen, Ebelman and others, it seems well established that the chief gases generated in the furnace, during operation, are nitrogen, carbonic acid and carbonic oxide, varying at various depths during full furnace action. But these variations are extremely irregular in different furnaces at the same height from the tuyeres and at the same depth from the mouth. This may result from the varying nature both of the ores and fluxes. Small quantities of hydrogen and of marsh gas are also found. In all cases of reported examinations in these experiments nitrogen was found most abundant at the throat, or tunnel head of the furnaces. Carbonic oxide was not abundant in most cases but in some carbonic oxide, as in one at Eisenerz, where eleven feet below the mouth the CO^2 was 16 per cent. and the CO 13 per cent. by volume, and 23 CO^2 and 12 CO, respectively, by weight. In another furnace in the same region CO^2 17 per cent. CO 13 by volume 24 and 11, respectively, by weight. In the first case the nitrogen was 70 per cent. and in the latter 69 at

the same places and times, respectively. This was probably due to special ores generating more CO^2 at these furnaces than at others wherein the ores were either not carbonates (sparry ores), or, were differently treated. In other cases, the average of several furnaces was (by volume) 6.26 CO^2 to 26.43 CO as at a furnace at Veckerkagen, Hesse Cassel, reported by Bunsen; 11.88 CO^2 to 19.62 CO at Bærum, Norway; in Clerval, France, 7.42 CO^2 to 29.55 CO.*

In American furnaces, the facts above stated would vary considerably, chiefly from the circumstance that the ores both in themselves and in the other members of the charges are different. But the practical suggestion, we would derive, from the large amount of CO^2 in any furnace using limestone is, that experiments, made at Ougrée, a village of Belgium, in 1849, by Levi and Schmidt, appeared to prove, with great distinctness, that there was not only an economy, but, an improvement in the metal made, by using calcined limestone, in other words, by burning the limestone. From a careful study of the gases produced at intervals of one foot along the curve of the furnace, these gentlemen came to the conclusion that 63 parts of lime substituted for 100 parts of limestone was the proportion to be adopted in the charges and the experiment on the large scale was adopted both in Belgium and in England and was spoken of highly as an actual saving in fuel after all the fuel consumed in both kilns of furnaces, was taken into account. The difficulty, in some of our furnaces, is, that so much foundry iron is used for purposes not necessitating this kind of care, that, in furnaces running foundry iron (not charcoal) commanding at this date (May, 1869) \$40 per ton, whereas the forge is held only at \$36, companies are satisfied and do not desire to make a change which at all opens up the way to the chance of a loss in time or money. Beside, an iron must have a reputation in the market to command a price, and this requires not only good metal but time. Hence, few will

* See minute report by Dr. Percy, p. 430 to 433.

attempt an experiment not so surrounded by guarantees as to prevent loss.

[Waste heat is an article so abundant in iron manufactures that a profitable method of using it should be deemed an object of considerable importance. Its application, owing to various causes, has sometimes been attended with only partial success. This partial success is to be attributed, in many instances, to the fact that it has been applied to the wrong place, and in the wrong way, in which cases the value of the heat will, of course, be underrated. If we consider the very limited capacity of iron for heat, and the high temperature at which the gases escape, the amount of heat wasted in iron works will prove to be immense. In a reheating furnace, for example, a small amount of the caloric generated would suffice to heat the iron to a welding heat; but a great deal of this heat is lost, because some time must elapse before the heat of the furnace can be imparted to the iron; besides, with the welding heat the flame escapes. The most important object of saving fuel in iron manufactures is to save time; if we gain one fourth of a given period of time, we save, in most cases, twenty-five per cent. of fuel. If we make six heats in a puddling furnace, instead of four, we save thirty-three per cent. If a reheating furnace of a given size can be made to produce eight tons of iron a day instead of four, nearly fifty per cent. of fuel will be saved. This is the true principle on which economy of fuel in iron manufacture is based. But, even when economy is carried to the furthest extent, we may imagine that the waste heat which is lost amounts to a very large per cent. of that generated. In employing waste heat, we are too apt to confound the quality with the quantity of heat. We see an immense amount of heat wasted; but we do not reflect that the temperature of this heat is very low, and that it is a want of intensity which makes its application limited. We possess no means to raise this temperature; at least, there are few instances in which it can be raised to such a degree as to make it useful in our manufacturing apparatus. Waste heat cannot be

generally employed, on account of the chemical composition of the flame, or gases, which contain the heat. The waste flame of the furnace contains a greater or less amount of free oxygen, or, at least, a large amount of watery vapors, which is the same thing, for these vapors are decomposed when in contact with hot iron. An excess of free oxygen, and low temperature are, in most cases, highly disadvantageous. For example, the waste heat of a reheating furnace would be of no more service than the flame from green wood. We cannot use it in a puddling furnace, in which inferior pig iron is converted. In most cases, its employment would interfere with important operations, in which case a loss would be experienced which the gain in fuel could not repay.

The waste heat of rolling mill furnaces may be advantageously employed to generate steam, and to propel rollers, hammers, squeezers, and blast machines. This is the case in the anthracite region generally, as well as in the rolling mills in the bituminous coal regions. In some cases, the waste heat is conducted in flues under the steam boiler; in others, the steam boiler is laid on the top of the puddling or reheating furnace, and receives the heat from the flue of the furnace before it enters the stack. Where anthracite, which is not easily kindled, is burned, the waste heat, after it passes the steam boiler, may be employed in heating, to a limited degree, the alimentary air for the grate. This will have a beneficial effect, for the waste heat increases the temperature of the furnace, and occasions a direct saving of about ten per cent. of fuel; duly estimating both advantages, the saving will amount to at least twenty per cent. Heating of blooms, and bar, or sheet iron, by means of the waste flame of other furnaces, is scarcely worth attempting, for the inconveniences attending this practice, added to the loss of iron which results, may, in most cases, counterbalance the gain in fuel. Nevertheless, where both skill and industry have been brought into requisition, the waste heat from reheating furnaces has, in some cases, been successfully employed in heating

sheet iron, by conducting the flame over a layer of coke or charcoal. The waste flame of the charcoal forges is quite bulky, but of very low temperature; it cannot serve with advantage for any other purpose than the heating of pig iron, and blast; but if this heating is well managed, twenty-five to thirty per cent. of coal may be saved. The best use which can be made of this flame is to apply it in the generation of steam.

The waste heat of the blast furnace is immense; we shall not greatly err, if we assert that 150 pounds of coal are used, where only ten pounds are actually needed to produce that amount of heat and gas which is required to revive and melt a given quantity of iron. Practical investigations on a small scale have shown that thirty pounds of coal are sufficient to produce 100 pounds of iron. Be this as it may, this much is certain, that an immense quantity of heat is wasted, to employ which various means have been resorted to. One of the most common applications of the top flame was, at one time, to the burning of lime; for this purpose it is excellently adapted, producing a fine article. The burning of lime is admissible at every furnace where heat is wasted; apart from the generation of steam, nothing is so well calculated to absorb the heat, which is otherwise of no use, as this process. The waste heat from the blast furnace is also employed to heat the blast; but the temperature of the tunnel-head flame is so high, that the heating apparatus cannot well be applied directly to the throat of the furnace; in this case, the conducting of the flame under a steam boiler, before it enters the hot blast stove, is a preferable arrangement. In some establishments of France and Germany, though not in this country, waste heat is employed in charring wood, in coking coal, or peat. Such an application is advantageous where the products of distillation, such as pyroligneous acid and coal tar, are of value. But this is the case only to a limited degree in this country. The charcoal or coke, which is then made in iron retorts, is inferior to kiln charcoal; and if the yield were as great in kilns as in these retorts, no profit would result from thus

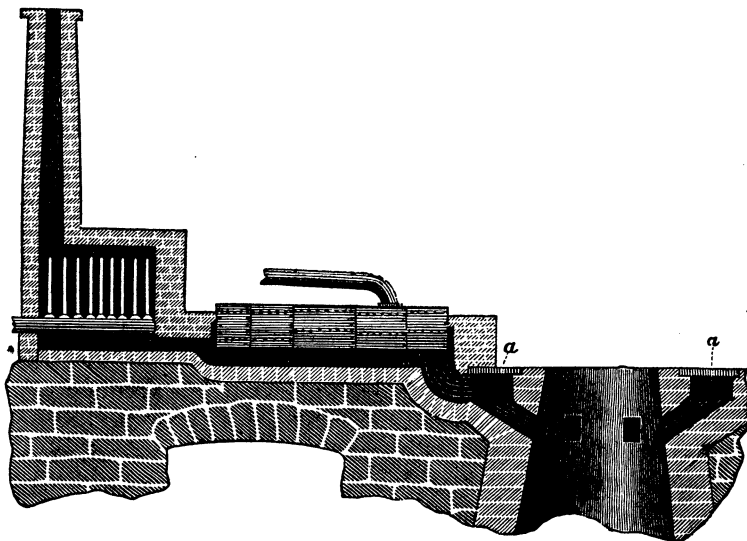
making charcoal, unless the products of distillation were worth the labor spent in obtaining them. An attempt has been made to apply the tunnel-head flame, at charcoal and some of the anthracite furnaces, to the roasting of ore. Where the waste flame is free of sulphur, as at charcoal furnaces, this application may be considered the best use which can be made of it. The waste flame from bituminous or sulphurous coal would not be of service, because of the facility with which it would carry sulphur into the ores. In roasting ores, heat of a low degree, steam, and carbonic acid are required. This is exactly the composition of most waste flames, and though it were not, they can be easily brought to that composition. From the top of the blast furnace, the heat may be conducted through brick channels to the yard, and discharged into the ore piles.

We repeat, the use of the waste flame deserves attention, in this country, not because fuel is expensive—for that may be obtained at a reasonable price everywhere, and at most places very cheaply—but on account of labor. The waste flame requires no attention, after an apparatus for employing it is once erected; in homely language, it is a fuel which requires no handling, no transport, no room—and therefore no labor. The use we make of it is quite significant; it serves the same purpose as labor-saving machines. The cases in which it may be beneficially applied are the following: In burning lime and iron ore, in generating steam, heating hot blast, burning clay for fire-brick, heating pig iron and metal for the forge and puddling furnace, and in burning brick and pottery ware; in fact, in all cases in which a large body of heat, though not a high heat, is required. For the manufacture of charcoal, coke, and for drying wood, waste heat can seldom be profitably employed.

At the charcoal furnace, upon the top of which there is a chimney that can be shut or opened by means of a damper, it is preferable to take the gas from the very top; but at the coke or anthracite furnace, the large throat of which makes a chimney impracticable, it is

advisable to tap the gas for the steam boilers and hot air apparatus a few feet below the top, so that the pressure of the blast may assist in driving the gas under the boilers. Fig. 121 exhibits such an arrangement. The

Fig. 121.



Tapping the gas from below the top.

gas, which is taken from a point three or four feet below the top of the furnace, is conducted by six or more holes (flues) into a kind of receiver *a, a*, which gathers the gas and conducts it to the steam boiler, or to any appropriate place. This receiver runs all around the air-wall of the furnace; the flues and the receiver should be made of fire-brick, and well secured. From the steam boilers the gas is conducted into the heating stove, for the purpose of heating the blast, and thence into the chimney, from thirty to fifty feet in height. This arrangement is generally adopted at the anthracite furnaces.]

CHAPTER IX.

FIRE-BRICK, REFRACTORY STONES AND MATERIAL.

[In this work, the terms *refractory* or *fire-proof* are used in quite a relative sense; if all matter which resists heat should be considered refractory, we would experience but little difficulty in making fire-proof brick or stones. It is not heat which destroys our furnace hearth or lining; it is not the intensity, the quality, of caloric which melts fire-bricks. The chemical affinity of the matter which we melt in an apparatus for the matter of which the apparatus is constructed is that which is most effective in destroying refractory material. Both silex and alumina are infusible, whether single or combined; but, if combined with potash or soda, they may be melted over a spirit-lamp. Lime, magnesia, and baryta form more or less fusible compounds with silex or clay, but cannot be fused together with pure potash or soda. The oxides of iron or manganese melt readily together with silex and alumina, but not with pure potash or pure soda. These are the principles by which we must be governed, in our efforts to make a refractory material. It is evident from this, that, if we heat potash, soda, lime, and magnesia, in contact with silex, the latter will be dissolved, in proportion to the quantity of the potash, to the intensity of the heat, and to the length of time it was exposed to the heat. If the amount of potash is small, a proportionally less amount of silex will be dissolved; for it is a well-established law of chemistry, that affinity increases with the predominating element. Time, and intensity of heat may be considered two agencies possessing similar qualities. What time cannot accomplish, heat will effect. Whatever deficiency exists in heat can be supplied by time. The oxides of iron and manganese act of course like potash.

The most refractory matters at our disposal are silex, clay, magnesia, lime, and baryta, and the silicates of these four alkalies. The most refractory are the silicates of alumina; next in order are the silicates of magnesia, lime, and baryta. Common fire-clay generally ranks as the first, soapstone second, and impure lime the third. We should carefully bear in mind what has been said, that any mixture containing more than two elements is more fusible than a compound containing only two; that is to say, with the increase of elements, the fusibility increases.

I. Native Refractory Stones.

Native refractory materials are sandstone, clay-slate, soapstone, mica-slate, gneiss, and granite. These minerals are, however, to a certain extent, compounds of various substances. It is, therefore, necessary to select them with care. Sandstone frequently contains iron, or lime, which, according to the degree in which they are present, augment or diminish its fusibility. The fusibility of the admixture can seldom be found by testing with acids; fire is our only reliance. What we have said of sandstone is applicable to all the other native materials.

a. Sandstone is quite abundant in this country, and is extensively employed. It forms the cheapest of all fire-proof materials, because, in addition to its abundance, and the facility with which it can be worked, it is less liable to melt and crack than any other native material. The coarsest kinds are the best, if they contain sufficient cement to keep them together. Certain fine-grained stones are excellent; but it is necessary to select them. The red sandstone, of the transition series, is generally good, as well as the millstone grit or the conglomerate beneath the bituminous coal. So great is the variety of sandstone in the western coal fields, that great care in selection is required. Less difficulty is experienced in the anthracite region. Connecticut contains a most beautiful kaolin, in a solid, stone-like form.

b. Clay-slate and shales serve, in many cases, for fire-brick. These materials, which are very much distributed over the United States, are generally more fusible than sandstones ; but they are preferable for those parts that are liable to sudden changes of heat ; such, for instance, as the lining and top of blast furnaces, hot blast stoves, steam-boilers and flues, roast ovens, and limekilns. In such cases, neither high heat nor chemical action is to be expected. Slates and shales may be found in abundance in the coal regions ; and by a little attention to color and grain, we shall soon be able to detect the best kind.

c. Talc-slate, or soapstone, is very refractory, but its brittleness impairs its utility as a fire-proof material. It is found abundantly in New Jersey, and in eastern Pa., as well as in several other States. It is employed as refractory matter in puddling furnaces, as is mentioned hereafter, but very seldom for any other purpose. None of the other kinds of native material, with the exception of fire-clay, are used in this country. In fact, those we have described, in addition to being preferable to any others, are found in such abundance as to render the employment of others unnecessary.

II. *Artificial Refractory Stones.*

Silex, clay, and lime are, in their pure state, perfectly infusible in any heat which we can easily produce. But we do not class these among the refractory materials, because they possess no adhesive properties, and cannot be brought to any compact form ; they always form a friable mass, which will be destroyed by the rubbing of fuel and tools against it. Therefore, the chemical nature and composition of a material are not the only qualities which render it fire-proof ; an indispensable element is its mechanical form. Burnt lime, perfectly infusible in any heat, would not serve the same purpose as fire-brick, because of its friability. Lime, prepared under the heaviest pressure of an hydraulic press, is scarcely strong enough to resist the gentle pressure of the oxygen-hydro-

gen flame of the Drummond light; it is not melted in this flame, but destroyed by the velocity of the atoms of the gas. The same is the case with pure siliceous or clay; when both are mixed together, a strong heat is required to form a kind of connection. All native material contains more or less water, which makes it liable to destruction by heat. Of all such materials, siliceous is the purest; next to this is clay. Clay always contains a large amount of water, which it retains with obstinate pertinacity; nor will a cherry-red heat expel it, unless the heat is of long duration. Water, however, will tend to make the clay porous, and thus diminish its utility as a refractory material. All our fire-clays, which are of good quality, and exist abundantly in the United States, are, if free of other matter, a composition of siliceous and alumina.

a. Fire-brick may be made like ordinary brick, with this difference, that the clay should be properly prepared previous to moulding it. Fire-brick is frequently baked in a kind of oven different from that employed for burning common brick; but this is a matter of expediency and economy, and has no influence upon the quality of the fire-brick. The clay used for this purpose may be tested by exposing a small piece of it, for an hour or two, to the strongest heat of a blacksmith's forge: if it retains its white color and does not become glazed, it may be considered fire-proof. There are two kinds of fire-clay; the one is solid, of a stony form, or like shale; the other soft, plastic. The first is found almost exclusively in the coal series; the second in all kinds of geological deposits, from the granite to the alluvial soil. The first is ground under iron edge-wheels, driven by a steam-engine or horse power, and it can also be pounded by means of stamp mills. It is frequently formed directly into brick and burnt; but in this case it does not make so good a brick as when, after the first grinding, it is treated like plastic clay. Plastic clay should be well mixed in a horse mill, similar to a common clay mill, formed into bricks or lumps, and then burnt by as high a heat as that applied in the final burning of the brick.

This heat expels nearly all the water from the clay, but hardly glazes it. After this, the clay is ground or pounded, and mixed with a sufficient quantity of fresh clay to make it adhere together. Bricks are then moulded from it, and burnt. A good fire-brick appears white, almost pure white, sometimes with a flesh-colored or gray tint. It ought to be slightly glazed, like good porcelain. The greater its specific gravity, the greater will be its durability.

Fire-brick ought to be as close in the grain as possible. If the brick are employed only in reheating furnaces, in the roofs and fire chambers of puddling furnaces, in chimneys in the lining of a blast furnace, or in air-stoves, closeness of grain is not of much importance; but with respect to the lining of the hearth of a puddling furnace, and the hearth or boshes of a blast furnace, it is of the first consequence. An open, porous fire-brick, or, in fact, any porous material which serves for that purpose, is very soon destroyed; the pores multiply the surface. The same relation exists between a close and a porous brick that exists between powdered material and solid matter. In such a condition, chemical solution of its parts is facilitated. Therefore, fire-brick employed in places where even the least destruction by chemical action is probable, ought in addition to being glazed, to exhibit as close a grain as possible, as well as to possess great specific gravity. The lining of a puddling furnace with fire-brick would be accompanied with great advantages; but every attempt to secure this result will fail, until fire-brick of proper quality are used. The addition of carbon, coke dust, and plumbago to fire-proof admixtures increases the fusibility of the brick, and, besides weakening, exerts an injurious influence in the puddling furnace. Plumbago is frequently mixed with fire-clay in making crucibles. It is added, not for the purpose of enabling the crucible to resist a higher heat, but for the purpose of preventing it from breaking, when suddenly cooled and heated. Such a crucible does not resist as much heat as one made of silicious matter; but the latter is very liable to break during or after the first

heat. The plumbago crucible, if well made, will endure ten or twelve heats in melting iron.

b. Artificial sandstone is an article very little used in this country; but as cases may occur in which it can be of service, we shall devote a short space to its consideration. At many establishments on the continent of Europe, artificial sandstones are used instead of fire-brick, and, strange as it may appear, they are used for hearth and boshes in blast furnaces. They can be made from any good, coarse, silicious sand, which does not melt in a high heat. Sand generally contains some foreign matter, particularly lime, of which even river sand is not free. Such matter must be removed. The surest method of procedure is in all cases, to burn the sand, pebbles, or native sandstone, in a cherry-red heat; the lime, which it may contain as a carbonate, may thus be burnt, when it can be removed by pounding and washing. In large iron manufactories, this branch of the business is quite an extensive one, and the mills for pounding and grinding receive considerable attention. Where coarse pure sand cannot be obtained, which is frequently the case, particularly in the coal regions, silicious or white river pebbles may be employed; or, if these cannot be had, white coarse sandstone, or millstone grit. This is burnt, pounded, and washed. The artificial sand, thus derived from pebbles or stone, is mixed with about one-fourth or one-sixth of its amount of fire-clay, or with just a sufficient quantity to keep the mass together after being dried. The finer the sand has been pounded, and the more tenacious the clay, the less of the latter which will be required. Before the clay is mixed with the sand, it is burnt and pounded. Clay should be burnt under all conditions, for raw clay contains a large amount of water. If once burnt, it will not absorb so much moisture as it previously contained. If fire-brick is made from clay containing a large amount of water, or from green clay, it will be porous; for the water which is evaporated from the interior of the brick of course occupied a certain space. If the pounded sand is too coarse, or if the grains are round, spaces will

be left between them, to fill which a large amount of clay will be required; in such a case, the stone will not glaze well, when exposed to heat. Therefore, the artificial sand and burnt clay are moistened with as little water as possible, and mixed together thoroughly; the latter object may be best effected by means of edge-wheels. The damp mass is formed into bricks in the common way. These bricks may have any form most conveniently adapted for our purposes. In rolling mills, specific forms are desirable for the various corners, angles, and arches of the puddling and reheating furnaces. After being stored under an open shed, and air-dried, they are ready for use. It would be a vain attempt to burn such an artificial sandstone, for the highest heat of the reheating furnace would scarcely glaze it, if the iron did not form a base; by this means, a glazing at the surface of the interior is effected. Such stones, if not cheap at first cost, are easily cut, easily laid, easily removed, and no loss arises from spalls or bats, for any unglazed remains of the stone are easily transformed into new brick again. However useful a material in the rolling mill, they are less adapted for the fireplace, and the lining of the hearth of a puddling furnace. The least touch with an iron tool will destroy them; but where no mechanical or chemical action is exercised, they are equal, if not preferable to the best fire-brick.

Of such artificial sandstones, the hearth and boshes of blast furnaces are built, and are said to answer well. If the raw material has been carefully managed, the statement may be true. We know that, in the coke blast furnace of Silesia, a similar mass is used, which is pounded into its place moist; the hearth forms a single sandstone. This kind of hearth is very durable, and commonly endures a blast of twenty-four months, and occasionally a blast even of four or five years. In the preparation of the mass, less reliance can be placed on its composition than upon the careful mixing of the compound. Air-dried stones may be of pure fire-clay; but these are not so durable as the sandstones of which we speak. These, as we have stated, ought never to

be made of green clay, even if the clay is of the best quality. Clay and silex, be it observed once for all, are the only serviceable materials for fire-proof stones.

c. The joints of fire-brick, sandstones, and artificial stones are to be thoroughly filled by mortar. The mortar ought to form a kind of solder between one stone and another, and may, for this reason, be more fusible than the bricks or stones themselves. Pure fire-clay is not a good mortar, for it cracks in drying, and leaves spaces, which occasion the destruction of the stone. A mixture of fire-clay and fine sand is preferable, not because it does not melt, but because it shrinks less in drying. The very best mortar for hearth-stones and fire-brick is made of a mixture of fire-clay and finely pounded blast furnace cinder; this mortar will cement stones and bricks firmly.]

Mr. Joseph Dixon of Joseph Dixon & Co., Jersey City, N. J., who is a very successful manufacturer of crucibles for steel melting, says, that the nearer a crucible comes to being all plumbago, the quicker it will melt, the plumbago being the conductor of heat, and not the other articles mixed with it to make a crucible. As it is impossible to make a serviceable crucible of nothing but plumbago, because plumbago has no adhesiveness, so, makers are compelled to mix it with clay to make it adhesive, or, to use the slang of the potter's trade, *tough* enough to hold together. The less clay is used the better. Some makers are now making crucibles by mixing less plumbago and making the crucible much heavier, in order to have them wear as long as those having a larger proportion of plumbago; but the greater the thickness and the less the conducting power of the substance between the metal and the fire, the longer it takes to melt and the more fuel is wasted. The French founders understand this point well, and they make their clay crucibles very thin, not more than half the thickness of the English. It is not merely the fuel, but the *time* wasted by a thick pot being used.

The fire-clay material at Amboy, N. J., seems to command considerable attention, and more lately, that of

Allentown, Pa., but we have found that, at Pittsburg, the Mount Savage, Md., fire-clay was preferred in some steel works to all others.

In review of this whole subject, it seems that the nature of the material of both the crucibles and the bricks should be determined in view of the object intended. The following which we have taken from the recent appendix of Petitgand & Ronna, on *Refractory Products*, comprises all that we deem important in addition.

The silicious element in these products constitutes the essential element in their composition. Berthier has prepared a table which presents the distinctive characters of these clays as follows:—

			Name of the clay.	Silex.	Alumina.	Iron.
Hessian	crucibles	. .	Gr. Almerode,	71	25	04
Beaufay	"	. .	{ D'Andenneset, }	65	34	10
Deyeux	"	. .	{ Abondant, }	72	19	4
English	"	. .	Shropshire,	71	23	4
Saint Etienne	"	. .	Salavas,	65	25	7
Bagneux	"	. .	Forges,	67	32	1
Bohemian	"	. .	Neuwelt,	68	29	2
Bricks of Creuzot	. . .		Aubin,	68	28	2

The above-mentioned authors state that no clay can properly be called refractory which does not contain an addition of cement, silicious compound, which modifies its primitive composition and renders it capable of sustaining the highest temperatures, and that the silex should be present in the state of natural quartz since the fusible elements combine less readily with aluminous bases. The above-mentioned name "cement" is a technical term, and signifies a different composition from that usually understood by that term with us. We give the composition below to illustrate what that is which is understood as a cement, in connection with another composition, the two forming as it is supposed the best material for hearth bricks.

Composition for Bricks.

		Parts.	Parts.	Parts.	Parts.
Cement,	Crushed burned fire-bricks	6	6	..	...
	Various other kinds,	...	...	4	3
	Pottery crucibles (debris),	...	1	...	...
	Calcined quartz,	2	3	...	...
	Clean coke,	1	0.50	...	1.50
	Calcined clay from Haltinne	4	...	2.50	4
	“ “ “ Vezin,	...	3	...	...
Foreign earths,	Sand, white and pure,	...	...	2.50	...
	Maizerouille,	9	8.50	...	...
	Tahier,	...	...	...	...
	Various clays,	...	...	3	3.50
Water	. . . . .	12	11	7	6
		22	22	12	12

The above will give a useful suggestion as to the manner of preparing special clays, or composition for bricks and crucibles for purposes wherein a great degree of resistance to heat is required.

CHAPTER IX.

BLAST MACHINES.

[THE means of effecting a favorable result in the application of fuel for the purpose of augmenting temperature, are various. This result can be accomplished by the simple application of chimneys, or of blast, or by using both together. Fuel is most perfectly used where it is oxidized in the highest degree; this oxidation takes place in the reheating furnace, where, generally, all the hydrogen is converted into water, and all the carbon into carbonic acid. We cannot say the same of any other apparatus, for we generally find a mixture of carbonic oxide, carbonic acid, and free oxygen, which is an evidence of imperfect combustion. Increased draught, or the concentration of more heat in the fire

chamber, will lessen such an evil ; but there is frequently a deficiency of draught in cases in which heat is necessary, as in that of the puddling furnace. If, in such instances, it is impossible to produce sufficient heat by the draught of the chimney, we are compelled to make use of blast machines. This is the case with anthracite coal and coke. How chimneys act in producing draught, and what are the rules to be applied in constructing them, are matters which may require scientific demonstration not included in our investigations. We have described the practical workings and dimensions of apparatus, which may be deemed sufficient for all practical purposes. An explanation as to the chemical effect of blast under different pressures, we shall give at the close of the chapter.

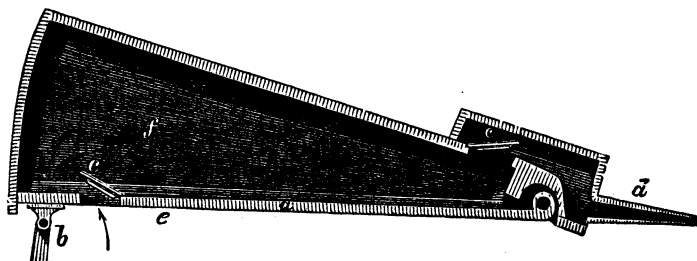
There are many forms of blast machines. We shall notice some blast machines in operation in Europe, which are frequently recommended by writers on metallurgy, principally for the purpose of showing their imperfections. The most simple blast machine is the smith's bellows, a description of which it is unnecessary to give.

I. Wooden Bellows of the Common Form.

A kind of blast machine, called Widholm's bellows, is very extensively used in Sweden, Russia, Germany, and France. We do not know that any are employed in the United States. As it works well, as the expense of its construction is small, and its application to the Catalan forge very simple, we shall furnish a drawing and description of it. Fig. 122 shows it in section ; *a* is the movable part or piston ; *b* an iron rod connected with a crank of the waterwheel, or the steam-engine ; *c, c* are the valves, and *d* the nozzle. The latter is fastened to the permanent top *f*, which is again fastened to some wooden framework. The whole has the appearance of a common smith's bellows, with the only difference that it is made entirely of wood. From ten to twelve strokes may be made in a minute, and two

bellows are required for one fire. The whole is from six to seven feet long and thirty inches wide—the piston

Fig. 122.



Swedish bellows.

having a motion of twelve inches. This kind of machine is applied to no other apparatus than the charcoal forge, and we allude to it merely because it is simple and cheap, fulfilling its purpose excellently.

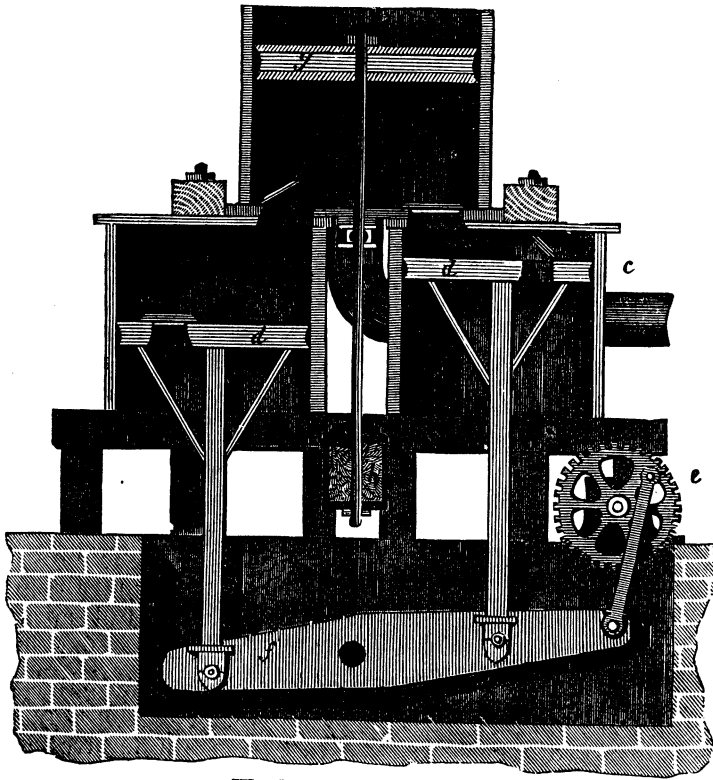
II. *Wooden Cylinder Bellows.*

These are of various forms. We have seen square cylinders and round ones: the piston playing from the top, or from below; or the piston working in both directions. There are vertical and horizontal cylinders, and machines working with one, two, or three cylinders, with a dry receiver, water receiver, or with no receiver.

Formerly there was chiefly used one form, the machine with two round tubs or bellows—the piston working from below, and a dry receiver placed on the top of the tubs. This may be considered the best form of the wooden blast machine, if but a single stroke is desired. Fig. 123 is a representation of a blast machine of this kind; *a, a* are the bellows; *b* the receiver from which the sheet-iron pipe *c* leads the blast to the furnace; *d, d* are the pistons, moved alternately by the beam *f*, which is set in motion by the crank and wheel *e*. The wheel may be moved either by a waterwheel or a steam-engine. From eight to ten strokes is generally the speed required to supply a charcoal furnace. The tubs or cylinders, as

well as the receiver, are generally from four to four and a half feet wide, and four feet high, making the stroke

Fig. 123.



Wooden cylinder bellows.

of the piston three feet. To the piston *g*, in the receiver, an iron rod is fastened, playing in a stuffing-box at the bottom, which carries a box *h* filled with iron or stones, to counterbalance the pressure of the blast, and to regulate it by playing up and down as the pressure from the tubs increases or diminishes. The valves are made of wood, lined with leather. The beam is generally laid below, and the tubs raised a few feet above ground. The whole machine is made of dry, well-seasoned wood—the cylinders glued: that is, composed of small segments of

dry pine or ash, an inch or an inch and a half thick; the woody fibre thus runs around the cylinder, *i. e.*, horizontally instead of vertically. This construction of the tubs secures greater permanency to their form. Their interior is in some instances, covered with a thin coating of a mixture of glue and plumbago, which gives it the appearance of iron, diminishes the friction, and secures a closer fit of the piston.

This kind of blast machine works admirably, if properly constructed; it is very durable. In every respect, this apparatus is preferable to the wooden bellows of the common form, such as that represented by Fig. 122. It can be erected at an expense of from \$250 to \$350. It will work one blast furnace for charcoal, or from four to five forge, or Catalan fires. A steam-engine or water-wheel of from twelve to sixteen horse power is required to put it in operation, and furnish the necessary blast for a blast furnace.

a. There are double working wooden tubs also in use, but not very frequently. These, in particular cases, may be of advantage; in cases, for instance, where room or expense is to be saved, or where wooden are very shortly to be replaced by iron cylinders. The wooden tubs are but a temporary arrangement, to gain time and means after the works are just started. The double working tubs, that is, those which make blast at each motion, like iron cylinders, offer no real advantages over the single; in fact, in ordinary cases, the tub with single stroke is preferable to the double tub. Among the advantages of the former, is the facility with which we can attend to the interior; in case damage is done to the surface of the tub, it can be instantly mended. This is not the case with double stroke cylinders; here the top and bottom are closed, and the interior is not accessible without stopping the blast machine, and the operations which depend upon it. For these reasons, tubs which open at the top are preferable to those which open from below. The principal objection against wooden cylinders is that they are frequently severely rubbed by the packing of the piston; this diminishes the pressure of the blast in consequence of the leaking between the piston and tub.

The disadvantages resulting from single stroke tubs, open from below, are more than counterbalanced by the greater simplicity of the piston rod, and the facility with which the valves can be adjusted. A stuffing-box is required, which, if the tubes are to be opened from above, must be made of iron. The expense of erecting a solid and strong frame to carry the crank and beam, is also comparatively great.

b. A good mechanic, and a thinking one, is required to construct a wooden blast machine. To put the wood well together is not sufficient; it is necessary to select it with due relation to its liability to twist, warp, and crack. All curly knotty wood, and wood from the heart of the tree, must be rejected. The circumference of the tree, or both seams of the heart plank alone, are to be used for the tubs and receiver. The tops as well as the tubs are generally three inches thick. The latter are glued together from segments one foot or more in length, and not more than one and a half inch thick, as before stated. The tops and pistons are composed of strips of plank not more than three or four inches wide, grooved and feathered, and well glued. Ash may be considered the best wood for making the tubs; but good dry pine will answer. Other kinds of wood, such as maple and walnut, are too apt to warp, and therefore ought not to be used. To keep the interior slippery and sound, the surface of the tub is frequently brushed over with plumbago, or soapstone powder, or with a mixture of both. These ingredients are moistened with water, to which a little glue may be added. Fat or oil is an improper material with which to lubricate the surface of a wooden tub, for both are very soon destroyed; the destruction of the piston and the wood of the cylinder then follows, to the injury of the machine, and the loss of blast.

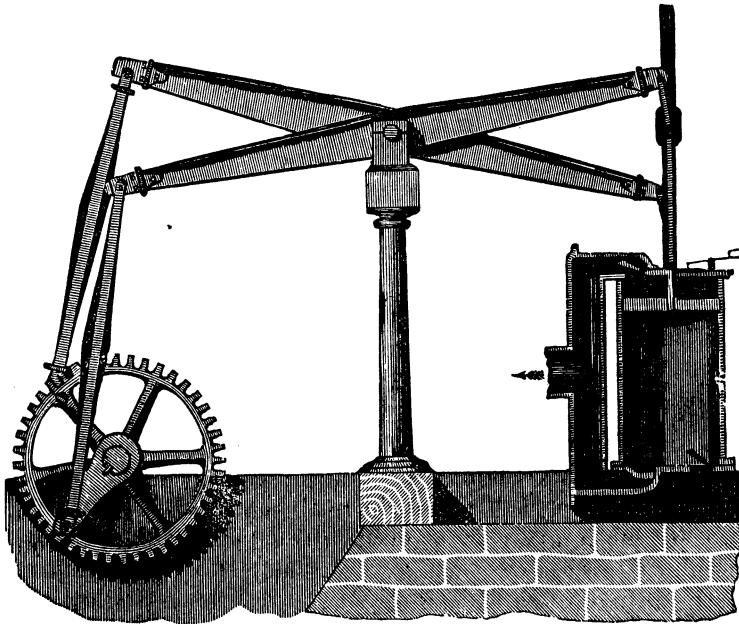
Square tubs, and horizontal tubs of double stroke, have been tried; but, it appears, with no good advantage, for nobody now thinks of such forms. It is unnecessary to speak of these machines in this place, as they belong to antiquity, and are, at the present time, of no practical importance.] One wooden blast bellows of the form above described, may yet be seen at the Oxford Furnace,

Warren Co., N. J. It was in service when charcoal alone was used as fuel. The date of the erection of this furnace is 1741.

III. *Iron Cylinder Blast Machines.*

[*a.* There are various forms of these machines. The smallest, but not the most simple, apparatus, is a double stroke cylinder—that is, composed of two beams and two cylinders—which is frequently met with at the Western establishments. In rolling mills, it is used to blow the finery; we find it also at some blast furnaces. Fig. 124 exhibits it so plainly, that a particular descrip-

Fig. 124.



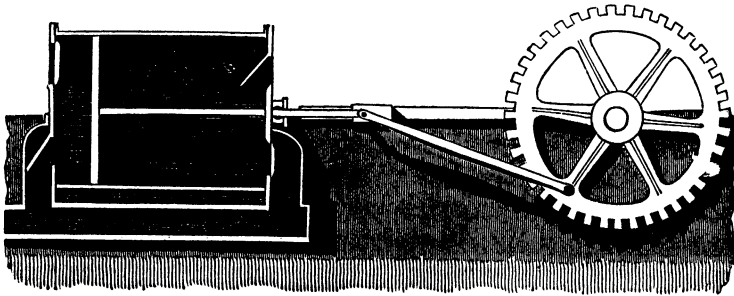
Simplest form of iron cylinder bellows.

tion of it is unnecessary. This machine makes an excellent blast. Its cost is the main objection to its use; this objection is valid, as far as the first outlay is concerned; but its expensiveness is counterbalanced by the excellent manner in which it works. It does not make

quite a regular blast, if worked without a receiver ; but even in this case, it may be made to work better than others differently constructed. In this machine, the cylinders, pistons, pipes, valves, wheels, and cranks are all of iron, except the beams and pitmans, connecting rods, which are of wood ; but the latter would be better if made also of iron. This machine is constructed on an excellent principle, and is superior to the horizontal cylinder, very much used in the Eastern States.

b. The desire of constructing a cheap apparatus has led to the making of an iron cylinder blast machine with a horizontal instead of a vertical motion of the piston, as shown in Fig. 125. There is no doubt that such a machine is far cheaper than one of vertical stroke ; but, when we consider the difficulty of keeping the packing tight, and the loss of blast which thence ensues, and the frequent disturbances which originate from hard rubbing of the piston on one part of the cylinder alone, it may be doubted whether it should be considered a superior apparatus ; Fig. 125 exhibits such a cylinder.

Fig. 125.



Horizontal cylinder blast machine.

The piston rod runs through both heads, to carry the weight of the piston, and prevent its rubbing with all its strength on the lower part of the cylinder. The valves are generally made of sheet iron lined with leather. Machines of this construction have their advantages, besides the great simplicity in their entire arrangement which they afford. There is no difficulty in procuring a solid foundation for the whole. The

weight of the piston, piston rod, and pitman, which is objectionable in verticle machines propelled by a water-wheel, particularly in those where but one cylinder is employed, is, in this case, almost balanced. The crank and a small portion of the pitman form the only weight which is not equipoised. The application of the valves is very simple, and very correct. They must be suspended vertically in a good blast machine.

The foregoing are the two leading arrangements involved in the construction of blast machines; both have their advantages and disadvantages. Where the propelling power is a waterwheel, and where it is contemplated to use but one or two cylinders, the horizontal cylinder may be considered to present many advantages; for, in such cases, it is always more or less troublesome to balance the weight of the piston, rod, &c. If the motive power is steam, the vertical position of the cylinder is decidedly preferable; for, in this case, the weight of the piston and its accompaniments can be balanced by the weight of the steam piston and its associated parts. A machine consisting of one blast cylinder and a receiver may here be considered the most simple and advantageous. Where a waterwheel is the propeller, it is less advantageous to employ a single cylinder, for, as the stroke is made by a crank, a great irregularity in the blast ensues, and a comparatively large receiver is therefore required to regulate the iniquities of the pressure. This is one of those instances in which a crank works to the disadvantage of the power applied, which is seldom the case. For these reasons, various forms of blast machines, propelled by waterwheels, have been tried. In this country, however, only those with two cylinders and double stroke are used. This makes a useful, but not an excellent blast, even though the cranks work at right angles to each other. A receiver is almost indispensable, in this case, to equalize the blast, and to make the best possible use of the water power. Blast machines with three cylinders and double stroke have been applied; and this arrangement may be considered the most advantageous where water is the moving power. Such a machine produces a very

steady blast, without a receiver, and gives the best effect of the waterwheel.

c. There is no reason whatever for employing water power in the propelling of blast machines at blast furnaces. There is abundance of waste heat for the generation of steam. The expense of erecting a steam-engine will be found less, in most cases, than that incurred in the erection of a waterwheel. For these reasons, we shall not dwell any longer upon the application of water power to blast machines, and shall confine our subsequent remarks to those propelled by steam alone.

IV. *General Remarks on Cylinder Blast Machines.*

There is no doubt that the application of one cylinder to a blast machine is accompanied with great advantages. Such an arrangement is in conformity with sound principles of mechanics, because, by this means, the least friction commensurate with the same effect is produced. Weigh the surface, the two most important causes of friction, are very greatly reduced. If the blast cylinder is on one end of a balance beam, and the steam cylinder on the other, the regularity of the blast is much greater. But this is no reason why a balance beam should be applied; because any inequality in the pressure of the blast can be regulated by applying a large receiver. If, therefore, it is found advantageous to abandon the balance beam, and still to retain the vertical position of the cylinders, the unbalanced weight of the pistons and piston rods is no obstacle. A piston rod, to connect blast and steam cylinders, has been applied where horizontal cylinders have been used. The hot part of the piston rod, playing in the steam cylinder, is thus cooled when in the blast cylinder, and the adherent oil dried when playing there. By this means, the hemp of the stuffing box of the former is very soon worn out. Besides this disadvantage, the close proximity of the steam apparatus and the blast cylinder is very injurious to the operations in the blast furnace. It is impossible to keep the steam out of the blast cylinder, if the latter

is too close to the steam cylinder or the steam boilers, or even if it is a very warm place. We know that moisture introduced into the hearth of a blast furnace is very injurious.

a. The size of a blast cylinder depends partly on the amount of air needed, and the number of strokes made, and partly upon the purposes for which it is designed. A charcoal forge requires from 400 to 500 cubic feet per minute; a finery from 800 to 1000; a charcoal furnace from 1000 to 2000; and an anthracite or coke furnace from 3000 to 5000. The number of strokes that can be made by a machine depends chiefly on the length of the stroke and the construction of the valves. In cylinders of four feet diameter, the piston can move with the speed of three feet; in smaller cylinders with greater, and in larger ones with less speed. If the motion is regulated by a flywheel and crank, more speed can be given than where a flywheel is not employed.

b. The size, form, and weight of the valves have a highly important influence upon the speed of the piston, loss of power, and quality of blast. The smaller the valves are made, the greater is the increase in the velocity of the air which is to pass through them. Friction of the air and valves, besides a direct loss of pressure and air in proportion to the pressure in the valve, is thus occasioned. One-twelfth of the surface of the piston is sufficient for the passage of the blast; but no disadvantage results if the valves are larger. The form of the latter has an influence upon the effect of the machine. Trap valves are the most practicable. Semicircular valves, with the hinges in the diameter, deserve to be more extensively employed than they are at the present time. The semicircle has less outline in proportion to the same surface than the square or parallelogram, the usual form of valves, and for this reason diminishes the friction of the air. Quadrilateral valves are seldom used. In general, the oblong shape is preferred, in which case, the hinges are put to one of the longest sides. It is obvious, from reasons which will be subsequently given, that the longer the valve, the more perfect will be its form. The weight of the valve is an important object,

for, if neglected, it may seriously injure the effect of a blast machine. It is easily understood that this weight may be so increased, that the effect of a blast apparatus amounts scarcely to anything. The weight of the valve causes an expansion of the air in suction; consequently, the pressure on the suction side of the piston in proportion to this weight will be less than that of the atmosphere. A loss of power and blast on the compressing side of the piston, proportional to the weight of the valve, is also occasioned. The air which remains in the dead space of the cylinder is of greater pressure than that in the blast pipes or receiver, in the ratio of the weight of the valve. To diminish the influence of this weight, the valves are generally placed in a vertical position, and are made entirely of a light material, such as wood and leather; they are also made as oblong as circumstances will admit. In this respect, the horizontal blast cylinder possesses great advantages. The location of the valves is best secured by vertical heads, and if the friction, or rather the weight, of the piston and piston rod could be balanced, the horizontal cylinder would be the best form of the blast machine. Their position and weight, also, have considerable influence upon the effect of a blast machine; but of still more consequence is the dead space left at the heads of a cylinder. Dead space is that which is not filled by the piston head, in its alternate motions, and from which the air that is compressed is not forced by the piston. In the best blast machines, the loss which this occasions amounts to at least ten per cent., and in some cylinders is as great as twenty-five per cent. The loss in power and blast increases with the size of the dead space. In this respect, the horizontal has the advantage over the vertical cylinder.

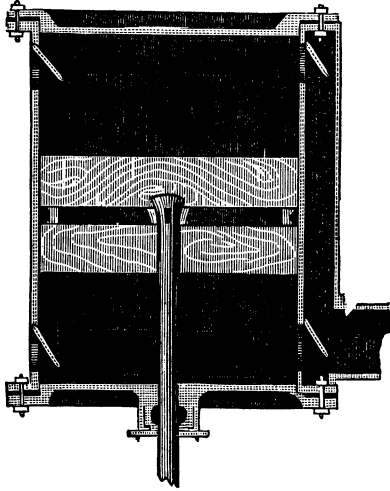
c. There are advantages connected with the vertical which cannot be reached by the horizontal cylinder, namely, a closer fit of the piston head to the cylinder, and less friction, as well as smaller loss by leakage. But as there are serious objections to it, on account of dead space, and of the position of the valves, we shall propose an improvement to the vertical cylinder which may

render it more acceptable. In a vertical cylinder, we cannot well place the valves at the top and bottom, because of their horizontal position; horizontal valves are thus rendered necessary. In small cylinders the valves are frequently horizontal; but large valves will not work well, if thus laid. To secure a vertical position for the valves, in a vertical cylinder, we are compelled to add valve boxes to the heads of the cylinder. Such boxes, of course, obstruct the passage of the blast, and occasion dead space—disadvantages, if possible, to be avoided. These may be obviated by the following arrangement: If the stroke of the piston is six feet, and the thickness of the piston head four inches, a cylinder six feet six inches long is required, to secure one inch space at each end. If we make the cylinder seven feet and a half long, instead of six and a half, a dead space of fourteen inches, or seven inches at each end, would be left. Around this space, and in the metal of the cylinder, a series of valves may be placed.* In this way, the number of valves may be multiplied to any extent we choose. The blast pipe is formed by screwing sheet iron or boiler-plate to the flanches of the cylinders, and by covering as many outlet valves as we choose to put in. The dead space caused by the excessive length of the cylinder is occupied by an increased thickness of the piston head; this thickness can be produced by a filling of light pine wood, or any other light material. The heads of such a cylinder will then be quite smooth. In the following illustration, Fig. 146, the arrangement is so clearly exhibited that no further explanation is required.

d. The piston, in wooden cylinders, is generally packed with leather, or hemp, or by a mixture of both; also, by filling leather hose with horse hair or wool, and by fastening this around the piston head into a groove, which is turned in the circumference of it. Packing in iron cylinders is performed like packing in steam cylinders. A steel or wrought iron hoop, a quarter of an inch thick, is laid around the piston head, and the space between the hoop and the head is stuffed with hemp or woollen material. In machines with vertical cylinders, we often

see the piston rod playing from above; but we quite as frequently see an arrangement by which the piston is

Fig. 126.



Blast cylinder, piston, and valves.

made to move from below. As far as the effect of the machine is concerned, this is merely a consideration of expediency and economy.

V. *Various Forms of Blast Machines.*

In no branch of human industry have more ingenuity and talent been displayed than in the construction of blast machines. Still, the greater part of such inventions were made with a limited knowledge of their purposes. Hence, an imperfection in most of the plans, though apparently well conceived, has been the consequence. The leading principles in this invention were generally reduced to the mechanical effect of the apparatus, that is, to obtaining the greatest effect from a given power, or producing the greatest amount of blast by the smallest means. Of the numberless variety of blast machines thus invented, there is but one which deserves our attention, in addition to the cylinder machines already described. This is the Cagniardelle, or screw

blast machine. Other machines, however extensively they may be employed, are, for our purpose, scarcely worth notice; they may serve in other metallurgical operations, but are not available in iron manufactories. Among these, are the Trompe, the Rosary or Chain-trompe, the Water column machines, the Gasometer bellows, and Barrel machines. These are the most common of this class. As there may be many readers who wish to know more than the names of these machines, we shall, as far as it is in our power, give a description of them.

a. The trompe, as well as the rest of this class, is driven by water; in fact, the water forms the piston, which compresses the air. The machine consists principally of two vertical pipes, the length of which is equal to the height of fall or head water. These pipes are slightly tapered, somewhat wider at the top than at the bottom. At the top of the pipe is the entrance of the water; it falls through a short conical pipe, which is somewhat narrower than the interior of the main pipe. In the main pipe, behind this short pipe or nozzle, are holes through which the air is drawn, which, after mingling with the water, is carried with the latter into a receiver; from this receiver, the water flows off, and the air is collected and conducted in another pipe to the furnace. This machine is based upon the same principle as that by which the draught in the chimney of a locomotive is produced. If we turn a locomotive chimney upside down, and turn water in at its top, we shall have a trompe, provided, several air holes are made in the chimney around the nozzle, and the lower part of it is set into a receiver which will retain the air, and permit the water to flow off.

b. The rosary, or chain-trompe, is an improvement upon the former. There is but one vertical pipe, which is cylindrical, as wide at the base as at the top. In this pipe moves an endless chain, over two pulleys, one at the top and the other at the bottom. To this chain, at certain distances, pistons of wood or leather are fastened, which move with it. If the head water is led into the pipe, where are always several pistons, it will move the

chains and pistons; and the pressure of the blast will be proportional to the distance between the pistons and the fall of the water. The air is collected into a receiver in the same manner as in the former case.

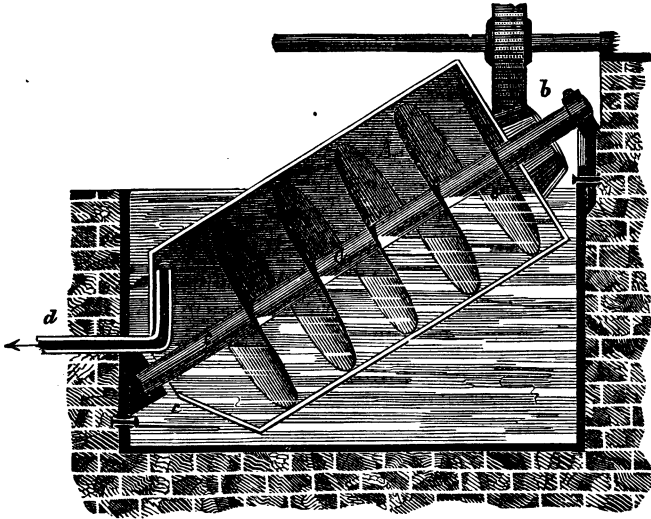
Water-column machines, of the most curious forms, and of a very complicated nature, have been invented. A great deal of ingenuity has been wasted upon a subject which will never reward the inventor.

c. Gasometer bellows are constructed like a common gasometer; the receiver is moved up and down by the engine, and by that motion blast is generated. A barrel-machine is a cylinder made of wood, resting horizontally in its longitudinal axis. Inside of the cylinder is a partition board fastened to the periphery on one side, and parallel with the axis. This partition divides the interior into two equal parts. The barrel is half filled with water, into which the partition board partly reaches. In the heads of the barrel are the valves for suction and compression. If this barrel is moved half-way round its axis, the air in the space between the surface of the water and the partition to which the latter is moving, will be compressed, and form blast. Of all these machines, not one deserves attention, because in all of them the air which forms the blast is continually in contact with water more or less agitated, which of course it moistens to excess. This is a sufficient reason for rejecting them.

d. The following apparatus suffers under the same disadvantages as those just described, namely, that its blast is moistened, on account of the water it contains. But its advantages over any other machine are so preponderating, that a skilful and cultivated mind may be advantageously employed in perfecting it. For this purpose, nothing else is needed than to replace the water by some liquid which is not injurious to furnace operations. The screw blast machine, or Cagniardelle, is represented by Fig. 127. *a* is a copper or sheet-iron hollow cylinder, resting on the two necks of its hollow axis. This cylinder, which may be from two to ten feet in diameter, is furnished inside with divisions, made by a sheet-iron spiral or screw, which is fastened to and

rotates with the cylinder, and is air-tight. It is secured to the cylinder and the axis. The head *b* is straight;

Fig. 127.



Screw blast machine.

but one quarter of it is open, which corresponds with the interior. The head *c* is a kind of conical dome, which is open all around the axis; *d* is a cast-iron pipe, which conducts the blast from the interior of the screw to the furnace, and the end of it within the cylinder is covered with a kind of cap, to prevent the falling in of drops of water. The whole machine is immersed in an iron trough, filled with water to the highest part of the axis. If the cylinder *a* is turned round its axis, the opening in the head *b* will be alternately under and above water; the first cell, which is formed by the screw, will be filled with water if the opening is immersed, and with air if the opening is above water. The air and water in the interior will move towards the lowest point of the cylinder; the latter is discharged through the opening *c*, and the first through the blast pipe *d*. The pressure of the blast corresponds to the difference between the water levels *e* and *f*, and depends upon the length and degree of inclination of the cylinder. The

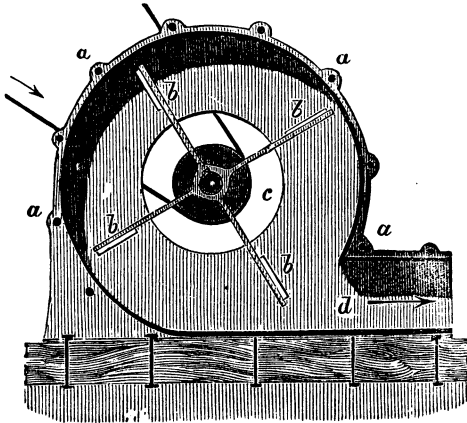
only disadvantages of this machine are, as remarked above, the contact between the air and water, which is very objectionable. Still, as we have stated before, its advantages are numerous. All is very simple; a perfect machine with rotary motion; no valves, or packing of piston; no loss of air; very little friction; no dead space; it gives a continual stream of blast of uniform pressure; it gives a better effect than any other blast machine, and finally, the power of the engine is applied to it to the best advantage.

VI. *Fan Blast Machines.*

These machines are very common in the anthracite region of Pennsylvania; they are used at steam boilers, and puddling, reheating, and cupola furnaces, where anthracite is burned; and at cupola furnaces, where coke is used for remelting pig iron, and founderies. Fig. 128 shows a section of a common fan. The two sides of the case are, in most instances, made of cast iron, and held together by the screw bolts, *a, a, a, a*. These bolts reach through both sides, and their length is therefore equal to the width of the machine, which varies from six to twenty inches. The space between the sides is occupied by a strip of sheet iron; this strip determines the width of the machine, and reaches all around the fan, forming the circular part of the case. The wings of the fan marked *b, b, b, b*, are of sheet iron; they are fastened to iron arms set upon the axis, and rotate with it, and they occupy a different position in different fans. Some are set radially, others inclined more or less tangentially. Some are straight; others have a slight curvature. On the whole, no marked difference between the one form of wings and the other results, so far as effect is concerned, if no blunders against the laws of mechanics are made. The fans with curved and short wings do not make so much noise as those with straight, radial, and long wings. The opening *c*, which receives the air, to be pressed out at *d*, must be of greater or less diameter, according to the size of the fan, or width of the wings. Broad fans require such an opening on each side. Small

fans, of but six or eight inches in width, work sufficiently well with one inlet. The diameter of a fan is seldom

Fig. 128.



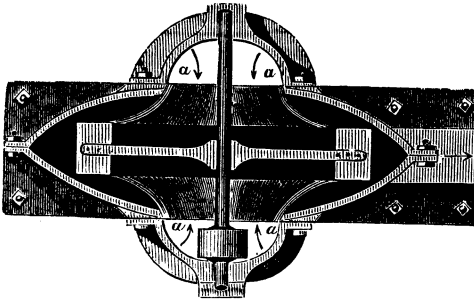
Common fan.

more than three feet, and from various reasons it can be shown that a larger diameter is of no advantage. The number of revolutions of the axis, or the speed of the wings, is very seldom less than 700 per minute; this speed may be considered sufficient for the blast of a blacksmith's forge, and small furnaces. At large furnaces, or cupolas, we frequently find the number of revolutions as many as 1800 per minute. The motion of the axis is produced by means of a leather or India rubber belt, and a pulley of from four to six inches in diameter.

a. Among the earliest forms in which fans have made their appearances, one which, some years ago, issued in Philadelphia, is as follows: The wings of this fan are encased in a separate box; a wheel is thus formed, which rotates in the outer box. Fig. 129 shows a horizontal section through the axis. The wings are thus connected, and form a closed wheel, in which the air is whirled round, and thrown out at the periphery. The inner case, which revolves with the wings, is to be fitted as closely as possible to the outer case, at the centre near *a, a, a, a*; for no packing can, in this case, be applied,

and there is a liability of losing blast, if the two circles do not fit well. This fan is decidedly better than the common fan, and is fast becoming a favorite of the public.

Fig. 129.



Improved fan.

b. As the building of this apparatus receives much attention in our machine shops, and as the leading principles involved in its construction are very little known, we shall designate such points as may be deemed of great importance by those who manufacture fans, which is frequently the lot of the iron manufacturer himself. The outward case should be strong and heavy; and the interior machinery, which revolves, as light as possible. For this reason, it should be made of the best wrought iron, or, what is preferable, of steel. Four wings produce quite as much effect as a greater number. It is, therefore, useless to exceed that number. The greatest attention must be paid to the gudgeons and pans; it is advisable to make both of steel, or, better still, to run the two ends of the shaft in steel points. The wings are to be exactly at equal distances, and of equal weight; otherwise, the strongest case will be shaken. The surface of each of the wings should be at least twice as large as the opening of the nozzle at the blowpipe.

c. The pressure of the blast from a fan is proportional to the square of the speed of the wings, with a given diameter of the fan. The pressure gains simply in the ratio of the diameter, or speed, provided there is the

same number of revolutions. The increase of speed is in the ratio of the increase of the radius. The pressure in the blast is produced by centrifugal force. The atoms of air, after being whirled round by the wings, are thrown out at their periphery by a force equal to the centrifugal force resulting from the speed of the wings.

This centrifugal force may be simply expressed by $\frac{C^2}{2gr}$;

C is the speed in feet per second ; g the speed of gravitation in the first second ; and r the radius of the fan. According to this, the effects of a fan ought to be far greater than they actually are ; therefore, a remarkable loss of power must take place in these machines. It is thus very clear that the increase of diameter augments the effect of the machine in a numerical proportion, while an increase of revolution adds to the effect in the proportion of the square. It is also very clear that an increased diameter greatly increases the friction, while the increase of speed does not augment it in the least. The frictions in these machines, is the greatest objection to their use ; therefore, the movable parts should be as light as possible. Friction increases in the ratio of the weight, where the materials are the same, but not with an augmentation of speed, at least not in the same ratio. From practical observation, the following formula has been deduced : in which a is the speed of the fan, that is to say, it represents the number of feet which the wings make in a second ; b , the surface of the nozzle ; c , the surface of a wing ; and d , the velocity of the escaping blast. This formula we conceive to be the proper dimensions of a fan :—

$$d = 0.73 \times \frac{a}{\sqrt{\frac{b}{c}}}$$

PRESENT FORM OF BLOWERS.

1. *Fan Blowers.*

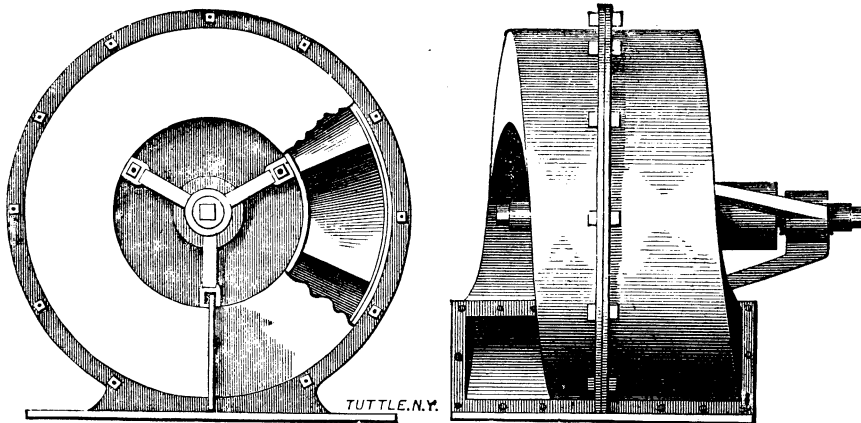
M. Alden's Blower, Philadelphia, is composed of a series of spiral curved fan blades or wings, set together in pairs and joined (in the direction of motion), so as to

form an acute, or knife edge, precisely after the form of the prow of a gun-boat, as the edge is seen through the delivery or wind-opening of the iron case. The fans or wings do not form a close fit to the sides or box of the machine, but set off a short distance. The fan-motion is accompanied with considerable noise.

F. P. Dimpfel's Blower, Philadelphia. This blower is characterized by flat rectangular wings or fans, which nearly fit the sides of the casing. It is apparently a more quiet fan than the preceding. It is quite a favorite fan in forge fires on the Lehigh and the Schuylkill Rivers. It is (in principle) used extensively at the coal pits for ventilation, in which case the movement is slower and it is much larger (from five to seven feet), than when used as a blower.

Farmer's Blower, New York. This is characterized by a spiral case, wherein with the same action of the internal wings the air received around the axle is de-

Fig. 130.



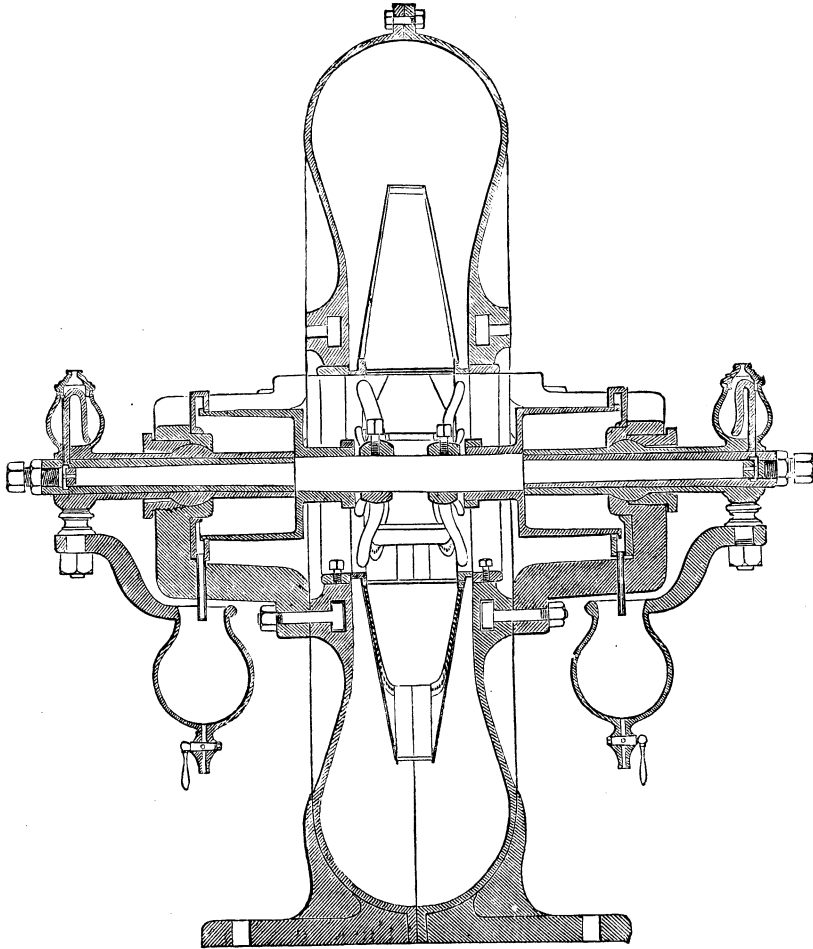
Farmer's fan.

livered in a spiral turn out at the side. The principle is good if the internal structure is such as to avoid friction or resistance. The blower has not been extensively introduced, but is highly spoken of at the Manhattan Gas-Works, N. Y. We have never seen it in operation.

Sturtevant's Bower, Boston, is characterized by curved

fans thrown back, or away from the direction of movement. This fan is very effective and almost entirely noiseless. The arrangement seems to be exceedingly perfect, and from the trials we have made of it, we are

Fig. 131.



Sturtevant's blower.

led to think that in all respects it is the most satisfactory of any of that class of blast machines called fan blowers.

Fig. 131 gives a full representation of all the parts, which show great completeness.

In Crookes' and Rohrig's edition of Kerl (1869) a fan somewhat resembling Sturtevant's fan, is figured (p. 601), but the curved blades or wings are cast with the wheel on one side, and throw the air, centrifugally, completely over the periphery of the wheel into the chamber on the other side and into a direction which is directly upon the continuation of the pulley shaft. It is neither so light nor effective as that of Sturtevant's. It is much used in Germany, and is constructed by Schwarzkopf, of Berlin, upon Schiele's principle, but making less noise than the last.

There is a certain velocity beyond which nothing is gained in any of these plans heretofore given. We have had a thirty-horse power applied upon a Sturtevant fan of 20 inches outside diameter for a short time and then reducing the power several horse-powers could discover no effective decrease in delivery, while the fan was intensely strained, and yet so far as the fan was concerned it has been running since for more than a year without any repairs, proving that while the instrument may bear the pressure, even without heating, there is practically no advantage in passing beyond certain limits. From four to ten horse powers are sufficient to run the usual sizes of these fans.

The Applications of these Fans.—They are especially useful in melting iron in cupolas, but they are employed extensively in our country for the puddling and reheating furnaces. They are adapted to charcoal furnaces where the amount of blast required can be met by the fan, as the pressure in all such cases is light, which we shall see more fully hereafter.

In Kerl's Metallurgy, as above referred to, it is stated that most of the fans used in the foundries at Berlin are 3 feet in diameter, and 15 inches broad; they are set in motion by a steam engine of six-horse power; they make 800 revolutions per minute, and provide three large cupola furnaces with the required blast

(about 2000 cubic feet) of three-fourths or one and a fourth lbs. pressure.

The quantity of blast required depends chiefly on the amount of the production, which again is influenced by the dimensions and construction of the furnace, and also depends on the nature of the fuel and the iron to be melted.

Coke cupola furnaces require from 400 to 700 cubic feet of blast per minute, according to the compactness of the coke, &c.; charcoal furnaces from 250 to 400 cubic feet. The pressure in coke furnaces amounts to from four to eight lines, and with charcoal from nine lines to two inches, and seldom less than six lines of mercury.* As each 100 lbs. of iron to be smelted per hour in a coke cupola furnace requires about 5000 cubic feet of blast, the following important data concerning the blast to be introduced, the diameter of the blast pipes, &c., will be useful:—

Pressure of the Blast.	Quantity of blast per sq. inch of the section of the blast pipe.	Section of the blast pipe per 100 lbs. of iron per hour.	Quantity of iron per hour and per square inch of the section of the blast pipe.
Water Inches.	Cubic feet.	Square Inches.	Pounds.
2.91	0.70	2.00	50
4.19	0.84	1.66	60
5.67	0.98	1.43	70
7.36	1.12	1.25	80
9.28	1.26	1.11	90

The following are some illustrations for the determination of the amount of blast:—

a. A cupola furnace has three tuyeres 6 inches in diameter; each is fed with blast of 7.36 inches of water pressure; how much iron can it fuse per hour? At the already stated pressure of the heat 80 lbs. of iron will result per hour per square inch of the blast pipe; three blast pipes, therefore, with 85 square inch section, will produce $80 \times 85 = 68$ cwts. of iron per hour.

b. How many square inches must be contained in the

* The pressure by mercury and water, is explained under *Manometer* in after pages.

section of 4 blast pipes; 40 cwts. of iron are to be produced per hour with a pressure of 7.36 inches?

As 100 lbs. of iron at the given pressure require 1.25 square inches in the section of the nozzles, 40 cwts. will require $40 \times 1.25 = 50$ square inches; therefore, each blast pipe must have a section of 12.5 square inches, or about 4 inches in diameter. •

The older coke cupola furnace at Lerbach (Hartz) having a blast pipe 5 inches in diameter, was worked with 600 cubic feet of cold blast per minute with a pressure of two and one-half or three ounces; the charcoal furnace, with a blast pipe of two inches nine lines diameter, was fed with from 395 to 425 cubic feet of blast of from 170° to 200° C.*

2. *Pressure Blowers.*

In the blowers already mentioned, the movement of the blast is not entirely due to the momentum given the air upon the principle of centrifugal force, but in some extent, and in some forms, upon the principle of the atmospheric movement observed when a railroad train passes into a tunnel or cut, namely, a condensation of air in front and partial vacuum in the rear. Or, more aptly, as in the chain pump, where the chain lifts the water when rapidly whirled. So that there is a quantum of pressure as well as of centrifugal force. Hence, some have called the previously mentioned fans *pressure blowers*. But, technically speaking, this is not correct, as we shall see upon further examination. The transition from the centrifugal force to the force produced by direct pressure of a piston may be illustrated by the following fan.

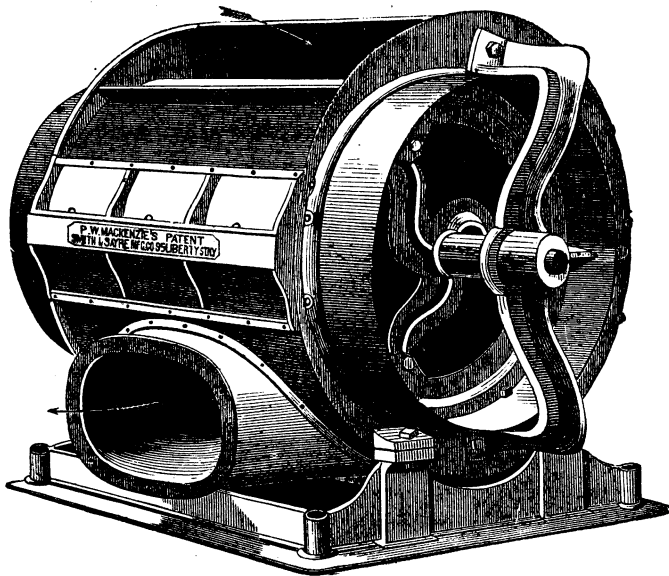
Mackenzie's Eccentric Blower, New York. The advantage of this blower is found in the fact that the revolutions need not be so rapid as in any of the former kind. It is also more of the nature of a pressure blower, whereas all of the former are fan blowers, and

* *Practical Treatise*, &c., pp. 603, 604.

depend, as previously stated, in part, or entirely, upon the centrifugal momentum given to the atmosphere by the motion of the fans or wings.

It is doubtful whether any greater practicable and economical pressure can be reached by any of the, strictly speaking, fan blowers, than one and one-half to two lbs. to the inch, although three lbs. pressure is claimed. Experiments, which are in process of trial, seem thus far to show that under the most favorable circumstances the above pressure is all that is available without injury to the machine if the pressure is made constant for any great length of time. In the Mackenzie blower (Fig. 132) the central cylinder centered on an

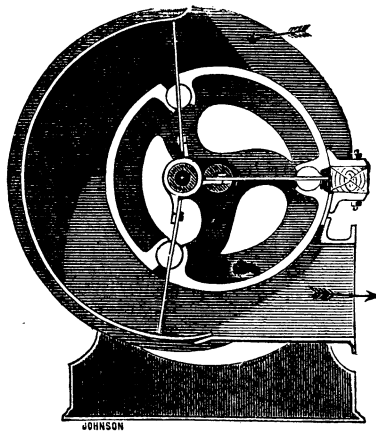
Fig. 132.



eccentric throws a portion of the body of that eccentrically moving cylinder closely against the external casing, so that with the wings (Fig. 133) it operates upon the principle of a piston, or plunger, in the steam cylinder, and, therefore, is a true pressure blower, and may require,

where pipes are all well fitted and tight, only 100 to 150 revolutions, while any fan blower of equal capacity would

Fig. 133.



require 1500 to 2000 revolutions. There is considerable clatter produced by this fan, and very little of the hum of some of the preceding fans. Nevertheless, where no higher pressure than one and one-half to two lbs. is required, the lightness with which the centrifugal fans may be run would make it more economical of power, and therefore advisable to use one of that class of blowers.

In all these species of blowers run by belts and band wheels there is a mechanical law which must be regarded. There may be leverage between the radius of the band wheel and of the fan or wing wheel of such a disparity as to make the expenditure of power greater than would be the case in the regular form of the piston blowing cylinder. We have little doubt that some fans have been constructed upon this mistake, in which case power is wasted, and it should be a point, when *pressure* is wanted over two lbs. of a constant and uniform nature and quantity, to study this liability and avoid it. There is a point where the relation of the radius of the band wheel to the fan demands an expenditure greater than

would be required in a blowing cylinder yielding *more air* on the same pressure per inch.*

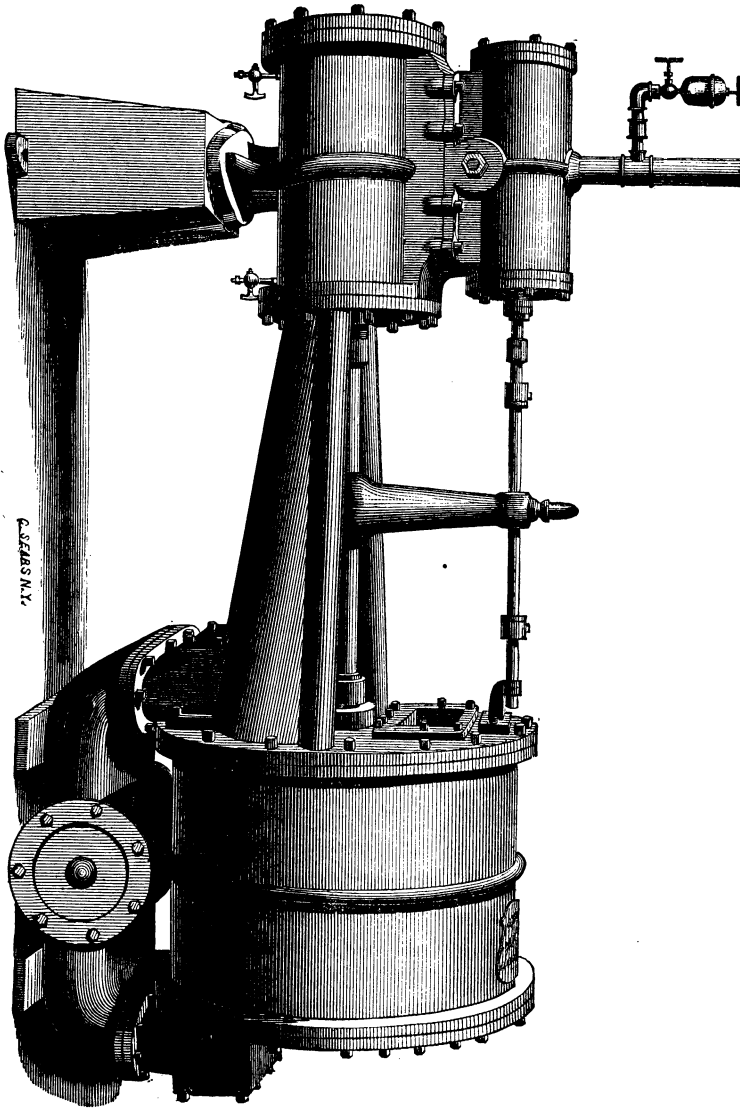
Fritz & Moore Blower, Philadelphia. There are two of these working at the Roberts' Iron Company's Works, Allentown, Pa., a description of which is as follows: One or more blowing cylinders and a steam cylinder placed upon the same bed plate, on the same level, and working in the same lines parallel to each other, the main shaft passing under the bed plate with a fly, or balance wheel on both ends, in which is a wrist, or shackle-pin, to which are attached two connecting rods which also connect with the crosshead, the crosshead working in guides placed above the cylinders and immediately across their centres, so that the piston rods of all the cylinders may be attached to the crosshead.

Earle's Patent Horizontal and Upright Air-pumps, South Norwalk, Conn. These blowers have given great satisfaction where a pressure blower is needed for special operations in the puddling and other furnaces, such as forcing air upon a pressure greater than can be accomplished by any fan. With regulating reservoirs they are extremely economical and move so quickly on the changes of direction in the piston that they are practically as constant as a fan. The following figure will illustrate them better than a description. There is no American blast engine which has a neater finish in all its parts coupled with greater efficiency, than that of the class represented by one which has just been finished and

* Some attention has been lately drawn to a method of creating a draught, as seen in a cupola furnace blown by steam jets, and constructed by Messrs. Woodward Brothers, the patentees, Queens Foundry, Ancoats, Manchester. There is no necessity in practice for regulating the draught by any alteration of the size of jet. The air is drawn into the furnace at the bottom through a series of circular openings, placed radially at two different horizontal levels.

Messrs. Woodward have constructed some jet cupolas with closed tops and a down flue passing outside the furnace to the bottom, and below the surface of the ground to the bottom of a chimney. In this construction the jet is applied to the bottom of the down flue, and works to some advantage on account of the reduced volume of gases to be drawn off from the spot at which they arrive at a considerably reduced temperature.—*Engineering*, Feb. 22, 1867.

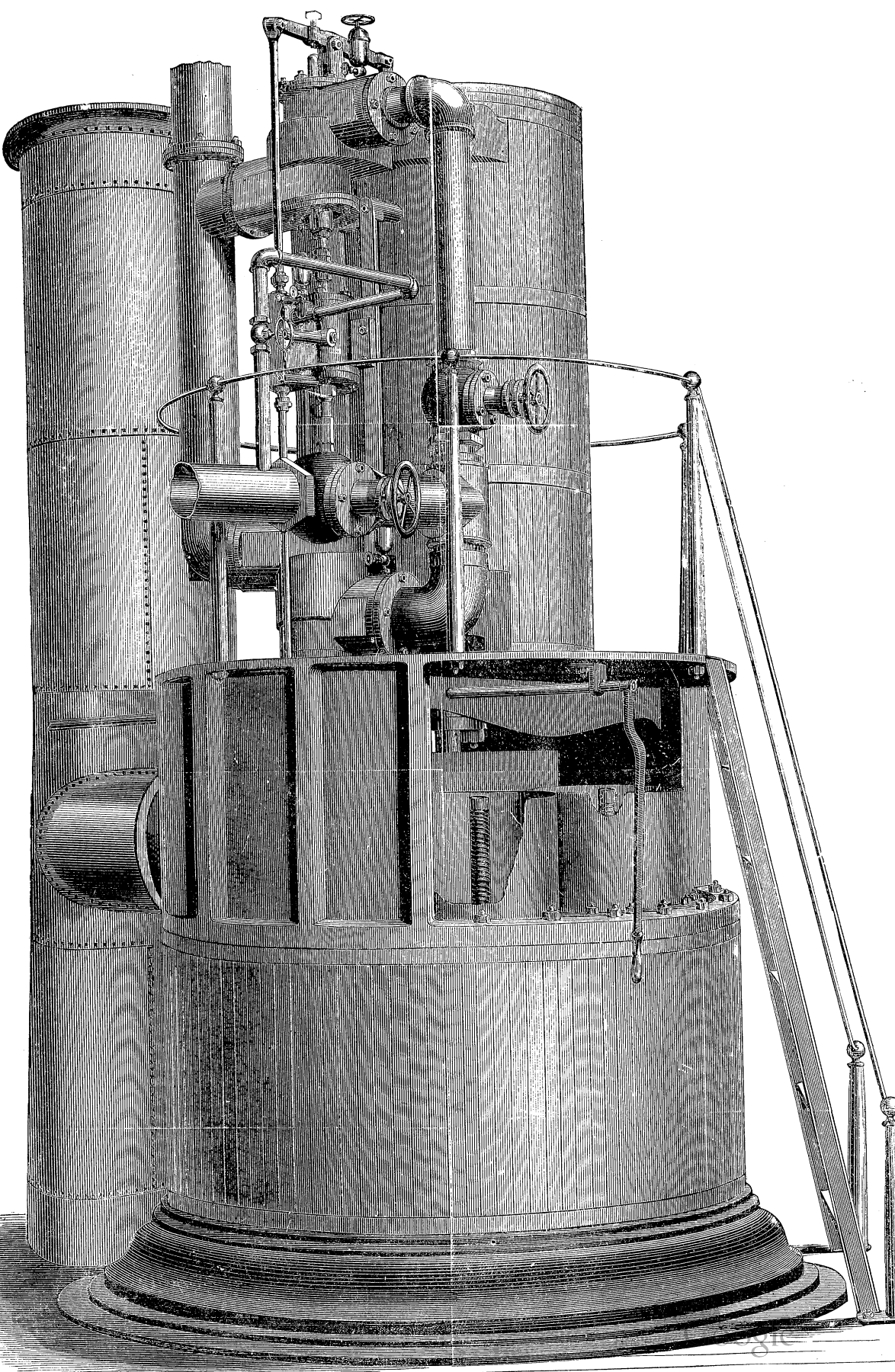
Fig. 134.



tried (May, 1869) at the above place in the presence of a number of ironmasters from Maryland and Ohio. The plan is spoken of as one of great excellence. Before the successful trial of the last made and one of the most im-

proved engines built for a Southern iron company, we received the following description from E. J. Hill, Secretary and Treasurer of the company :—

“We are now building an engine of 72-inch diameter and 8-feet stroke, with a steam cylinder 36 inches in diameter, and this machine we expect will give six pounds pressure through six 3-inch openings, and that, too, with lower steam pressure than any other steam engine which has been built up to the present time. This engine we shall have completed in three or four weeks. The new engine will have some very important changes in it. First, the air piston and follower, instead of being cast iron and having the packing between, will consist of a ring six inches in thickness, with space for packing, which will be of solid wool felted and set out by a spring ring. Instead of the one piston rod taking the piston in the centre, there will be three taking hold of the outside of the air piston, passing up through the head, outside of the steam cylinder, and fastened to a crosshead, which is itself fastened to the piston rod coming up through the top of steam cylinder. The great advantage of this is that it entirely prevents any steam or water from being carried down the piston rod through the stuffing box into the air cylinder. Again, the air piston, instead of being like ordinary pistons, of cast iron and very heavy, as would necessarily be the case if one piston rod carried it from the centre, is simply an outside ring, this ring being held by the three rods, and the entire centre being covered with boiler iron slightly concaved. The large trough between the two cylinders is entirely done away with, the steam cylinder resting upon three legs, which legs themselves rest upon brackets cast upon the sides of the main air cylinder. An important fact, which was omitted in the description given in the papers, is that the steam cylinder is cushioned at both ends by the piston passing and closing the exhaust ports just before the termination of the stroke, thus rendering striking the heads absolutely impossible, besides making the change of stroke



almost instantaneous, and in consequence of this the variation in the blast is little or nothing.

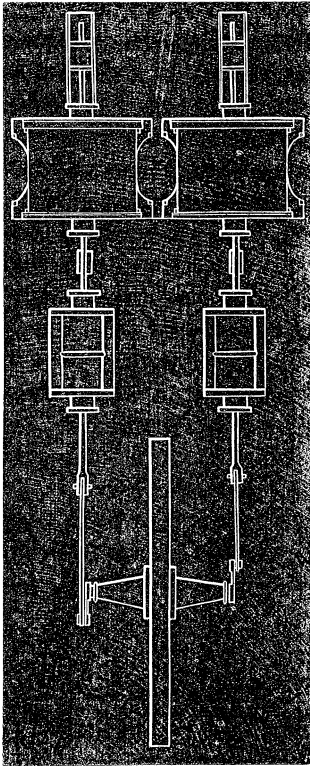
"The cost of the one now building will be \$8000. The engines are highly finished, both cylinders being covered with black-walnut sheathing and brass-banded with brass stair rail. The main piston, as well as the valve pistons, are both provided with combined spring and steam packing rings, the valves being balanced piston valves, and cushioned in the same manner as the main piston."

We have already spoken of the blast engine and cylinder at the Saucon Iron Works, Hellertown, as perhaps of its kind (beam engines) as compact and complete a plan as any we have seen of Morris, Towne & Co.'s engines. In this engine the main supports of the walking beam are used to convey the blast to the main regulator. (See Fig. 105). The largest blast engines are those at Catasauqua and Hokendauqua—whose dimensions we have given (p. 200). The next in size and power appear to be those at Scranton, the steam cylinders of which are 54 in. and 56 in.; the blowing cylinders 86 in. and 93 in. To represent these engines would take more space than we can afford for beam engines, and, comparatively speaking, vertical and horizontal engines are more in use. At the Carbon Iron Works, Parryville, Carbon Co., Pa., on the Lehigh, is a very neat vertical engine, which works well. In examining this engine, we were led to suppose that a considerable amount of power was lost in many engines, by too narrow an opening in the blast cylinders for the entering air, and thereby the movement of the piston is checked because of a vacuum, and a corresponding power is lost. This engine *seemed* to labor under this disadvantage, from the peculiar sharpness or intensity of sound produced in the movement.

Various forms of vertical and horizontal engines, where the works are not of the largest character, seem to be in growing demand. The following is a very simple plan of double cylinder adapted for small works or large. It is a horizontal engine, and the Fig. 135 explains itself. It is of an engine adopted at Hörde, Westphalia.

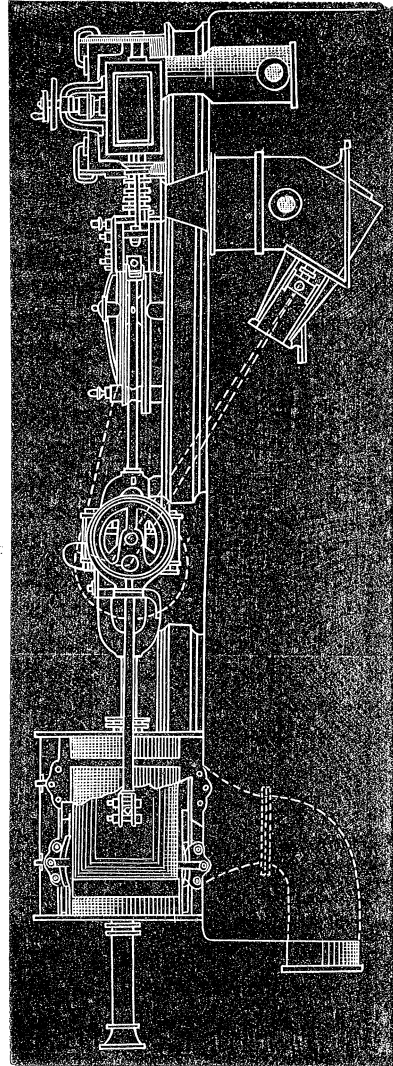
The engineer recommends that the engine stroke should not exceed the diameter of the blowing cylinder; that the piston be as light as possible; that the dimensions of the blowing cylinder should be such that in the normal working the velocity of the piston should not exceed about 250 or 260 feet per minute; that the opening for the air

Fig. 135.



Horizontal blast engine.

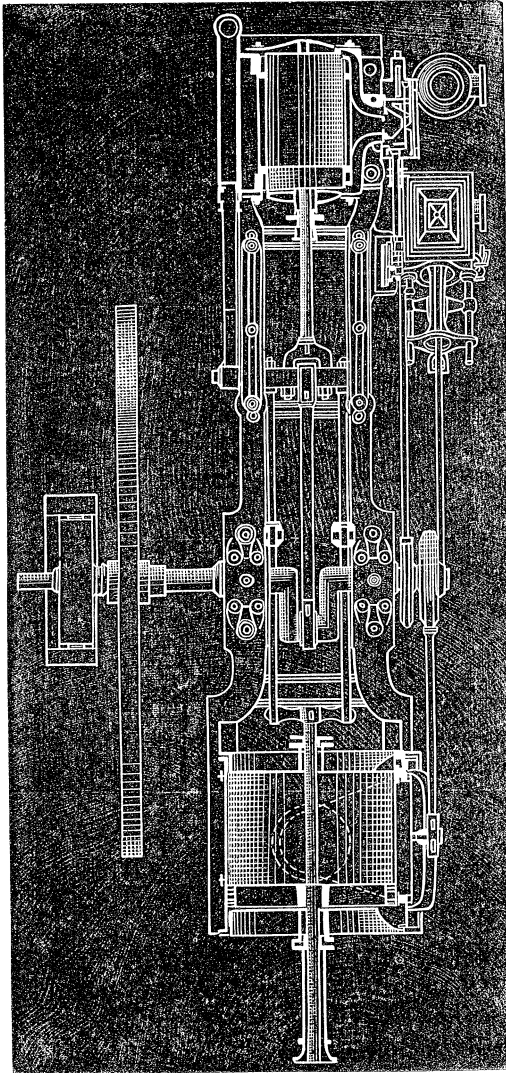
Fig. 136.



Horizontal blast engine. Thomas & Laurens. Elevation.

entrance should be carefully made sufficiently large for air and at least one-eighth the area of the piston; and that the foundations of the engine should be perfectly solid. Another form of great completeness may be seen represented in a blast engine, of 120-horse power,

Fig. 137.

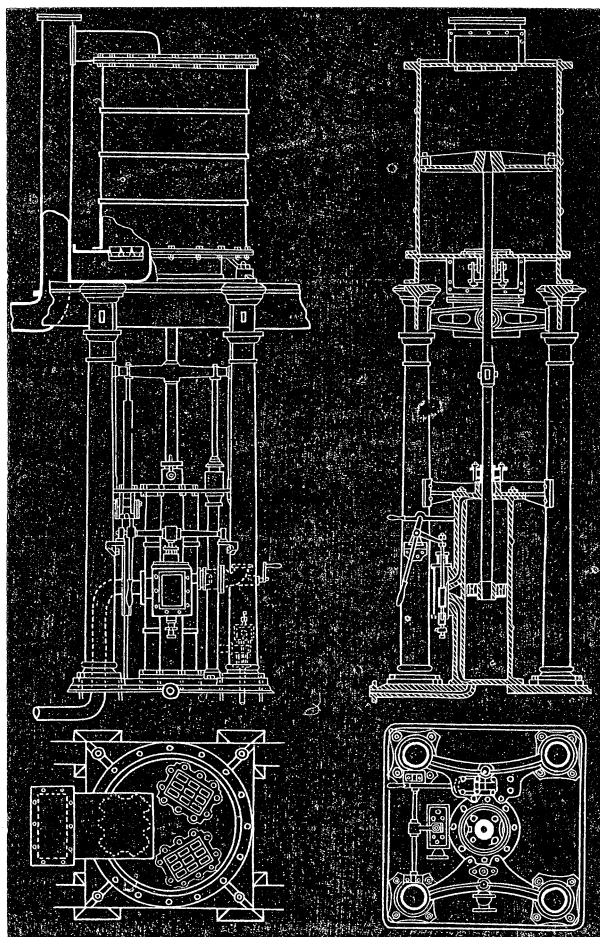


Horizontal blast engine. Thomas & Laurens. Plan.

of Messrs. Thomas & Laurens, wherein the same piston rod connects both pistons of steam and blowing cylinders. Fig. 136 the section and elevation. Fig. 137 is the plan.

Of the neatest and most satisfactory vertical engines,

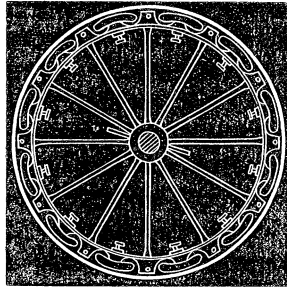
Fig. 138.



Vertical blast engine. Reschitza, Austria.

Figs. 138 and 139 may be presented as a good representative type. It is an Austrian blowing engine of 20-

Fig. 139.



Piston-spring packing.

horse power and one of the direct action. Diameter of steam cylinder 15.82 inches, diameter of blowing cylinder 49.80 inches, stroke 56.06 inches. Number of revolutions per minute 30.*

CHAPTER XI.

RECEIVERS, OR REGULATORS OF BLAST TUYERES, VALVES, &c.

[CYLINDER blast machines, as well as those of the common bellows form, make an irregular blast. The back and forward motion of the piston, which, when it arrives at the culminating points, ceases, for a few moments, to make any blast at all, of course causes an interruption of supply to the nozzles, and a consequent waving, sinking, and falling, in the pressure of the blast. Uniformity of pressure is so important an object at the blast furnace, that too much attention cannot be paid to it; but our attention commensurate with its importance this subject has never received. If there were no other argument to convince the skeptical; if we had no facts to prove directly the great value of a uniform pressure, the consideration that different pressures are necessary

* Messrs. Petitgand & Ronna.

in blowing different furnaces ought to settle the question conclusively. We know that one kind of charcoal will permit a pressure of but half a pound, while another kind requires a pressure of one pound and more. In each case, too great or too little pressure is injurious. Where the coal is of such a nature as to require but three-quarters of a pound pressure, we are obliged to secure that amount. If, as not unfrequently happens, we make, in the same stroke of the cylinder, a difference of between a half a pound and a pound, we destroy fuel uselessly, for that blast which is below three-quarters of a pound, as well as that which is above it, is only a waste.

Regulators of blast, commonly called receivers, are of various forms. Scientifically, they may be divided into three classes: the wet receiver, or water regulator; the dry receiver, with movable piston; and the air chamber, of constant capacity. The wet receiver is not to be recommended, on account of its water. Though this water should be covered with floating oil, or other matter, as has been suggested, the receiver would not be adapted for use.

a. The second class, or the dry receiver with movable piston, is generally employed in blast machines with two wooden cylinders; and in some machines, with iron cylinders. The top of a common blacksmith's bellows acts on the same principle and belongs to this class. The receiver is more perfect than the first kind, but it is far from producing a uniform pressure, or at least that uniformity the blast furnace requires. For forges, such receivers answer very well. In Fig. 123, a receiver with a movable piston is shown. Its dimensions should be very nearly those of one of the cylinders. If the diameter is increased, the play of the piston, and consequently the resistance, are diminished; the latter is the cause of the irregularities in the blast. If the dead points, caused by the raising and falling of the piston, could be obviated, this receiver would be useful; but, as that is not likely ever to be the case, there is little

probability that this apparatus will ever become a favorite among the blast furnace owners.

b. The air chamber of constant capacity is coming more and more into general use; this is unquestionably the best of all regulators. Air chambers of various forms have been tried: that the best form is the sheet-iron cylinder may now be considered a settled question. In order to make a good, uniform blast, this receiver should be of great capacity; if sufficiently large, the blast is perfect. Partly from considerations of economy, less frequently from those of expediency, wooden, stone, or brick chambers have been used. Vaults cut into rock, or native caves, have also been used as blast regulators. All these experiments have furnished no inducements for imitation, because the difficulty of keeping such chambers air-tight was too great to be overcome. Consequently, most of the stone and wooden chambers have been abandoned, and iron ones constructed. At the present time, air chambers are made of sheet iron one-eighth of an inch thick, and of greater or less capacity, according to the number of strokes of the piston of the blast machine, and the capacity of the cylinders.

It would lead us too far to enter upon a thorough investigation concerning the capacity of a dry receiver; but we shall point out such facts as have a bearing upon the question. The dimensions of the air chamber have, in no respect, any relation to the capacity of the blast cylinder. This is influenced by other circumstances. The irregularities of pressure are less where two blast cylinders are working than where but one is employed; the result is still better where three are used. In the latter case, the blast is generally so uniform that no receiver is needed, and the employment of large pipes to conduct the blast to the furnace is all that is required. With two cylinders and double stroke, the blast ought to be nearly uniform, according to theoretical calculations, if the weight of the piston is counterbalanced. In practice, we find that these machines answer excellently for fineries and hard coal, while they are insufficient for soft charcoal, and for well regulated smelting

operations. Blast machines, with two double stroke cylinders, but without beams and counterbalance, must be adjusted by direct balance weight, because the united weight of the two pistons is too great even for a large air chamber. To set the cranks opposite each other in such a machine is not advisable, for the difference in pressure is so great that it cannot be effectually overcome by a chamber. Two cylinders and single stroke require opposite cranks. A blast machine with a single cylinder requires the largest possible air chamber, particularly where a waterwheel or an expansion steam engine is the motive power.

The dimensions of the air chamber in a double cylinder machine and double stroke is sufficiently large if made of ten times the capacity of one of the blast cylinders. With one cylinder, or two single stroke cylinders, from twenty to thirty times the capacity of the cylinder is required. If large air-pipes are employed, and if the distance from the blast machine to the furnace is considerable, the capacity of the pipes may be taken into account. Where the pipes are narrow, they do nothing toward equalizing the blast; on the contrary, they cause a loss in power by friction.

The form of an air chamber is generally that of the cylinder, like a steam boiler, and varies from four to eight feet in diameter. It sometimes has straight, sometimes convex heads. The globular form has, in some places, been adopted, but we do not think that this form will ever be used extensively in this part of the world. The thickness or strength of the sheet iron for an air chamber is made to vary according to the pressure of the blast; but, as the strongest pressure would hardly tear iron one-eighth of an inch thick, and as that thickness is required to give stability to the form of the chamber, the question is one of slight practical interest. An air chamber should be provided with a safety-valve, to guard against accidents, as well as with a manhole, to afford an opportunity of getting into the interior, if that is found to be necessary. The air chamber, unless too small, is the best of all regulators. If we have any

doubt in relation to what should be its capacity, it is always better to make the chamber too large than too small.

Blast Pipes.

It is seldom or never in our power to bring the blast generator close to the tuyere. Conductors are generally required to lead the blast from the blast machine to the furnace. Various forms of conductors have been invented, such as wooden and iron pipes, of a round, square, and polygonal section; but at present, scarcely any other than sheet or cast-iron pipes are employed. At forge fires, and small blast, puddling, and reheating furnaces, or at those places where but little pressure is required, pipes of tin plate are used, but where stronger pressure is needed, as at charcoal blast furnaces working hard coal, and at anthracite and coke furnaces, pipes of sheet iron one-eighth of an inch thick, or of cast iron, are used. Cast-iron would be preferable, in many respects, to sheet-iron pipes, but, in consequence of their weight, the latter are coming more and more into general use. Sheet-iron pipe can be made of almost any length, and it has an advantage in the small number of its joints. The diameter of the pipes varies according to the amount of air which is to pass through them. Where 1000 cubic feet of air per minute are to pass through one of medium length, the diameter should be at least ten inches. Each additional 1000 feet should have the same space, so that 4000 feet per minute require a diameter of twenty inches. If the distance from the blast machine to the furnace is more than 100 feet, the diameter of the pipe is to be increased; and it may be doubled with each additional 100 feet, in consequence of the friction of the air. A very appreciable loss of blast results from narrow pipes.

Cast-iron pipes require many joints; they are liable to leak, in consequence of the destruction of the cement in the joints, caused by contraction and expansion; this is particularly the case in long pipes. For cold blast pipes, the best joint we can use is the leaden one com-

monly employed in light gas pipes. Where hot air is to be conducted, as in the use of hot blast, the lead is liable to melt by the heat of the air. In this case, the joints must be cemented by a fire-proof material. A cement which resists the influence of hot air is composed of iron filings, turnings, or borings, worked through a riddle or a coarse sieve, to make it uniform. Seventy-five pounds of sifted filings are to be mixed with one pound of powdered sal-ammoniac and one ounce of flowers of sulphur, to which two pounds of clay in dry powder must be added. The whole of these ingredients must be well mixed together, and kept in a dry place for use. Whenever any cement is wanted, some of the dry and prepared material is moistened, and used immediately; for, as it very soon oxidizes, it is adapted to make good joints only when it is fresh. A few days are required to harden this cement; but, when thoroughly indurated, it is almost as durable as the iron itself. If pipes with couplings are used, which are preferable to those with flanges, care must be taken that the space between the couplings and the pipe is not too great; one-quarter of an inch all around is sufficient. Where the space is excessive, the expansion of the cement, occasioned by the oxidation of the iron, is very apt to break the couplings. Long, straight pipes are very liable to leak, because, from their length, they are stretched by a high heat. By reason of their weight, expansion and contraction break the cement of the joints. Such pipes should be laid upon a well-levelled and paved foundation, and rested upon rollers, which may be either short pieces of round bar iron, or short pieces of two inch cast-iron pipes. In long conductors, the expansion and contraction of the pipes are frequently neutralized by sliding couplings, or stuffing boxes. This is a necessary precaution where hot blast is to be conducted a considerable distance. Elbows should be avoided as much as possible in blast pipes; and if necessitated to use them, the corner should be turned in as large a circle as possible. The loss of power of the blast, when suddenly turning round a corner, is very great. Acute angles, and even

those of 90° , are, if possible, to be altogether avoided. The best location of blast pipes, where they are weak, and liable to break, or where the joints are not quite safe, is above ground. For well-constructed and properly cemented pipes, the best situation is below ground. But we ought to take the precaution of laying them in well-constructed, spacious channels, walled and paved with brick or stone, and covered with wood, stone, or cast-iron plate. When laid in the ground and covered with earth, they are very liable to be injured, and seldom answer a good purpose. It is better to lay them above ground than to inclose them in an immovable position. Though corners of any kind are to be avoided in blast conductors, we must not, therefore, suppose that very straight pipes are the best form we can select. A gentle bend is advantageous, for it will tend to preserve the joints. Various plans of locating the blast pipes around a blast furnace have been adopted. In some instances, we see the pipes above the head; in others, walled in the pillars; and in others, again, below the bottom stone of the hearth. The latter plan is preferable; but, unless executed with due care, the result will be unfavorable. A blast pipe thus laid should be entirely free, that is, it should be at liberty to move exactly to that degree which the difference of temperature to which it is exposed inclines it. If this precaution is taken, we experience no trouble with it. An objection has been raised against laying the pipes in this manner, because, in some cases, hot cinder and hot iron have found access into the channels for the pipes. But such accidents cannot be deemed a valid objection. They can be avoided by a judicious plan of laying the pipes, and by proper care in the management of the furnace.

a. The mouth-pieces of the blast pipes, called nozzles, are tapered sheet-iron tubes, varying from one to four feet in length, according to locality, and the purpose which they serve. At one end, they are as wide as the conducting blast pipe, to which they are joined; at the other end, they are as wide as is considered necessary for the passage of the blast. These nozzles are fre-

quently divided into two parts ; one of which is permanent, and the other, generally the shorter, movable. This facilitates a change in the dimensions of the nozzles. These conical pipes are either welded or soldered with copper, for, as they are narrow, rivets will obstruct the blast, and make it exceedingly noisy. Where cold blast is used, the nozzles are generally connected with the main blast pipe by a leather bag. This bag is held to the pipes by means of an iron hoop. This hoop, of the form of a wristband, is tied to its place by a screw, which, by drawing the hoop close to the leather, and that to the pipe, makes an air-tight joint. Where hot blast is employed, leather cannot be put into the conducting pipe. In this case, everything must be metal. It frequently happens that the nozzles are to be temporarily removed ; to facilitate this removal, and to avoid loss of time as much as possible, a joint is required. With cold blast, the motion of the nozzle from one place to another is frequently necessary, and more or less dip is required ; for that purpose, the leather-bag connection is indispensable. With hot blast, this is not the case, and therefore movable nozzles are unnecessary.

The size of the nozzle is, under certain circumstances, a matter of great importance, and deserves more attention than it generally receives, particularly at charcoal blast furnaces, and charcoal forges. If the moving power of the blast machine is limited, then it is the opening of the nozzle which determines the pressure of the blast. As a given pressure is more advantageous, it is evident that the size of the nozzle must have considerable influence upon the smelting operations. The changing of nozzles must be conducted with reference to securing a permanent pressure, for this is indispensable. The amount of blast may be increased or diminished. The diameter of the nozzle is of course subject to great variations. We employ nozzles of one inch diameter at charcoal forges ; from one and a half inch to two and a half inches at charcoal furnaces ; and from three to four inches diameter at coke and anthracite furnaces. Where other things are equal, the nozzles for

hot blast should be larger than those for cold blast. The form or taper of the nozzle at the point is a matter of considerable consequence; the greater the taper, that is, the larger the angle of convergence towards the point, the more the blast spreads into the furnace. Its results are similar to those of a weaker blast. An application of this principle is made at the charcoal forge, and in some places of the Old World, at the blast furnace, by employing two nozzles, which blow in such directions as to spread the blast in a greater degree among the hot coal. Stronger blast may be thus applied to soft coal, in which case it is advantageous. The more cylindrical the form of the nozzle, the greater the degree in which the blast will be kept together in the furnace. This form improves the pressure of the blast. Similar results take place where only the extreme end of the nozzle is cylindrical to a length equal to the diameter of the opening. That is, a three inch nozzle requires a cylindrical nose three inches long to form a compact column of blast; and a two inch nozzle requires a nose two inches in length. Cylindrical nozzles are preferable for hard coal; tapered nozzles for soft coal, charcoal forges, and fineries. Long and narrow tubes occasion much friction; therefore, it is advantageous to make the nozzles as short as possible. The current of blast is moulded at the very extreme end of the nozzle.

Tuyeres.

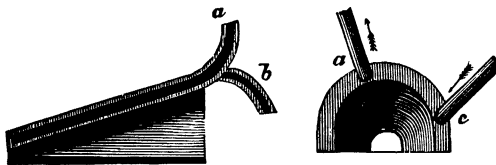
Before puddling was so generally introduced as at present, the shape and position of the tuyere at a blast furnace received considerable attention; but, since the quality of pig iron has been sought for with less anxiety, the tuyere ceases to be of much importance. The chief purpose of the metallic tuyere is the preservation of the fire-proof hearthstones; the direction and form of the blast are of minor importance. This protection is accomplished, in some measure, by making a coating of fire-clay in the tuyere holes, which is cut in the hearthstones. By this means, constant attendance, and re-

peated renewal with clay, will enable us to keep the tuyere narrow. No tuyere, whether of clay or metal, should ever be wider than the nozzle. Where one of the former kind exceeds the width of the nozzle, it burns away, and the hearth is exposed to destruction. The preservation of the original dimensions of the hearth is the main object which the manager of a furnace seeks to secure; and, as the clay tuyere does not effect this object, tuyeres made of copper or cast iron have been substituted in its place. These reach farther into the furnace than the clay tuyere, and, therefore, as it is decidedly of advantage that the blast should be driven as far as possible into the centre of the hearth, they are much preferable to the latter. Wrought-iron tuyeres are liable to burn. The iron, in consequence of the purity, oxidizes, and forms with the clay around it a very fusible silicate, which is precipitated into the furnace. Gray is preferable to white cast iron, and also to wrought iron; the carbon and impurities it contains protect it against oxidation and destruction. Copper is the best metal for tuyeres; it is a good conductor of heat, and is kept cool by the blast more easily than iron. Its silicates also are infusible. If copper oxidizes, and forms a silicate, the latter will protect it. The advantages derived from the copper tuyere have, in Europe, been acknowledged for more than a century; still, the charcoal furnaces in this country, at which cold blast is employed, are generally blown by clay tuyeres, the result of which is the waste of a great deal of coal, and the production of inferior iron. We do not recommend the application of the copper tuyere, for the water tuyere is preferable; but mention the above fact as a curiosity; as, in fact, one of those rare cases in which our citizens do not make the best use of the means at their disposal. The copper tuyere is protected against the heat of the furnace by the cold blast, which touches it, and cools it; for this reason the tuyere should not be wider than the nozzle. In this point of view, we may regard the tuyere as a prolongation of the nozzle, in which case, of course, it is governed by the rules applicable to the latter. So

long as pig iron is to be made for the charcoal forge, the desire to make white plate iron in the blast furnace will exist. It is very difficult, almost impossible, to keep a blast furnace constantly running upon a certain kind of iron; therefore, the difference which the quality of that in the furnace exhibits, is modified to a more or less general standard by means of the position of the tuyere, such as its direction and inclination. Very skilful management is required, in many instances, to produce the desired effect. In some parts of Europe, where cold blast iron for the forge is manufactured, the copper tuyere is yet in use; but where pig iron for puddling is made, or hot blast employed, the tuyere will not require close attention. In this country, we can scarcely appreciate the niceties involved in adjusting the tuyere, not even at the forge fires; but this adjustment is unaccompanied with any practical convenience, for the trouble it requires is never compensated. The advantages which arise from a scrupulous attention to the tuyere are, at best, very small; and such attention would, under the conditions which exist in this country, especially the high price of labor, result in loss instead of gain.

a. At cold blast furnaces, in this country, clay or cast-iron tuyeres, principally the former, are generally employed. Water tuyeres are in use at forges, fineries, hot blast, and at some cold blast furnaces. A common tuyere for the Catalan forge, the charcoal forge, finery, and charcoal blast furnaces, is made of boiler-plate; it is represented by Fig. 140. The top part is hollow,

Fig. 140.

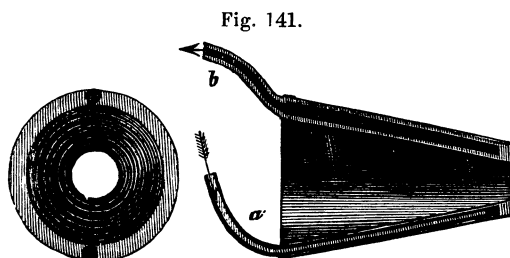


Section and view of a water tuyere with flat bottom.

while the bottom part which is generally flat, as shown at *c*, is solid. A water pipe of one-half inch bore con-

ducts a current of cold water through the hollow top; this preserves the tuyere, and protects it against burning. The bottom is made flat, so as to serve as a support to the nozzle; we are thus enabled to move the latter to those places where it is most needed. At blast furnaces and fineries, this precaution is not of much use, for the nozzle remains at the place where it is fixed; but at forges it must be movable. Both of the water pipes are, in most cases, at the top; this arrangement can scarcely be considered so advantageous as that in which one pipe, or the entrance of the water, is nearer the bottom, and the other pipe, or the outflow, at the top.

b. Tuyeres for anthracite, coke, and most of the charcoal furnaces, are perfectly round, and made of boiler-plate; also of copper or cast iron. Fig. 141 shows a



Round water tuyere.

round water tuyere; this may be two inches wide at the narrowest point, as at charcoal furnaces, or from four to four and a half inches, as is the case at anthracite furnaces. The taper of the tuyere does not affect the furnace, and, for all the evil this tapering occasions, it may be a perfect cylinder. In using hot blast, it makes no difference how the air is conducted into the furnace, provided the end of the tuyere is kept open, and bright, which is all that is necessary. The nozzle is laid into the tuyere—how far it reaches into it, is a matter of no consequence—and the space between them filled up with clay. At a cold blast furnace, it requires some attention not to push the nozzle too far in, or to draw it too far back. The water pipes, marked *a* and *b*, may be of

lead, three-fourths of an inch, seldom one inch, bore; one on the lower, and the other on the top part of the brim. The lower pipe conducts the water to the tuyere, and the upper conducts it from the tuyere. The former is, in many cases, pushed as far as possible into the interior of the tuyere, to bring the cold water into the furnace; the water is thus applied where the heat is greatest. A constant, uninterrupted, supply of water is necessary to prevent the melting of the tuyere. The water must be pure; else it will leave a sediment in the tuyere which is sure to cause its destruction. There must also be a sufficient amount of cold water; for, if the formation of steam is going on in the interior of the tuyere, the latter is sure to be burned. Copper and brass last longer than iron; but if iron tuyeres are well made, and soldered with copper, and if there is no lack of water, they may last a long time. Where there is deficiency of water, or where there are sediments in the interior of a tuyere, a few hours' heat will destroy it. If we find that the tuyeres do not stand the heat, our attention must be directed to the water; if nothing appears wrong, the application of larger pipes, or higher hydrostatic pressure, will then remedy the evil. Water tuyeres are generally from ten to twenty inches long; tuyeres that are too short are liable to be burnt, by the fire working around them, because there is not sufficient room to keep it closed up. Another disadvantage of such tuyeres is, that their want of length prevents them from being pushed into the hearth; but length is necessary when the hearth is burned out, and when we wish to carry the blast further into the interior. The external size of the tuyere is a matter which requires attention in its construction. The total surface determines the amount of water which is necessary to keep it cool. The larger the surface, particularly the diameter, the greater the amount of water necessary, and of course the greater the danger of burning. A tuyere is seldom more than four inches in inside diameter; and we frequently see tuyeres whose diameter outside is twelve, and even more inches. In this, there is something wrong, for with the

increase of the diameter is the augmentation of the danger.

Tuyeres may be considered a prolongation of the nozzle or the blast pipe, and disconnected from it merely for the sake of preservation, and of more convenient access to the interior of the furnace. Cold blast should taper more than hot blast tuyeres, because the former clinker in a greater degree, and require cleaning more frequently than the latter. The more acute the angle of the tuyere, the colder it works; the more tapered it is, the hotter it works. These observations are of practical importance. In most cases, we want the blast as far in the interior of the furnace as possible, because fuel is thus saved, better iron is produced, and the hearth protected. There is some difficulty in giving cold blast tuyeres a slight taper, because they should be very wide outside; but this difficulty can be overcome by making the interior of the tuyere curved. If its extreme end, as far back as the diameter of the mouth, is cylindrical, the same purpose is accomplished as though the whole tuyere was a cylinder. If the tuyere is too much tapered, which is shown by its working too hot, we lessen the evil, in some measure, by pushing the nozzle further into the furnace. This is but a temporary, not a radical, remedy; tuyeres of the proper form must be substituted. If the tuyere works too cold, that is, sets on too much cold cinder, our only resource is scrupulously to keep it clean, and to replace it as soon as possible by a more tapering tuyere, or a more obtuse cone. From these considerations, it is evident that different kinds of ore require a tuyere of different taper; for the exact degree of this taper, no general rule can be given. Experience must, in this instance, be our only guide. This will appear more evident, if we consider that the kind of fuel and the pressure of the blast must also be taken into consideration when we construct a tuyere. Calcareous ore, as well as the pig iron made from it, works naturally hot at the tuyere; consequently, we employ acute tuyeres: these serve to drive the blast far into the furnace, by which means they will be kept cool. This result can be

effected by a water tuyere. Clay ores—which work naturally cold at the tuyere—work better with a tuyere that is tapered, in which case, a water tuyere is not so favorable. These considerations have a special bearing upon the working of furnaces and forges, and are of an entirely practical nature. For this reason, the management of the furnace or forge is accompanied with such different results. It is evident that the modification of a tuyere cannot, at times, be so quickly accomplished as we desire. Months, and even years, are often consumed, before the required form can be determined; in many cases, this form is never arrived at. The shape of the tuyere is, therefore, a matter which, at blast furnaces, generally depends on the decision of the keeper or founder; and as the clay tuyere may be altered very conveniently, this may be assigned as one of the reasons why so many tuyeres of this kind are in use. The whole matter is divested of its mystery, if we reflect that an obtuse tuyere tends to work warm, and an acute tuyere to work cold. The latter is more advantageous than the former, as respects both the quality and quantity of work; but it is more difficult to manage. But, as the form of the nozzle, as well as that of a metal tuyere, is permanent, the latter may be a dry or water tuyere; and as the advantage of either shape can be arrived at, in a more or less perfect manner, by pushing in or drawing back the nozzle, no solid objection exists against metal tuyeres. In these cases, there ought to be a difference between the forms of the nozzle and that of the tuyere. An obtuse nozzle should work with an acute tuyere; a slightly tapered nozzle with a greatly tapered tuyere. The latter form is generally preferred, on account of the facilities it offers for cleaning the tuyere.

In applying hot blast, the form of the tuyere and the nozzle is a matter of indifference; still, while constructing them, it will do no harm to take the above rules into consideration. The advantages of hot blast are sometimes doubtful. It may be as well to unite, by means of perfect forms of apparatus, all the advantages deriv-

able from cold blast ; we can thus regain what is lost in quantity by its employment.

We have spoken of the relative advantages of a greater or less number of tuyeres in the same apparatus. In forge fires, we generally observe but one tuyere and two nozzles. At refinery fires, we often see the tuyeres all on one side ; at other places, on opposite sides : in one tuyere we see two nozzles, and in others but one. All these differences are the result of local causes, originating in the form of the apparatus, the quality of the iron and fuel, the pressure of the blast, and the qualification of the workmen ; these causes will be clearly understood from our previous investigations. The number of the tuyeres, and their position in the blast furnace, are of sufficient importance to deserve our attention. In the same chapter, we remarked, that, in using cold blast, we should employ as few, and in using hot blast, as many tuyeres as possible. Cold blast tuyeres are naturally troublesome ; they are apt to become black ;* they require constant attention, as well in moving the nozzle as in patching the tuyere with clay ; they tend to produce white iron, and they cool the lower parts of the hearth. For these reasons, we would reduce the number of these tuyeres as much as possible. The hot blast tuyere works very hot ; occasions but little trouble ; is inclined to produce gray iron ; and tends to reduce siliceous, and consequently may produce a poor quality of iron. Therefore, we recommend the use of as many hot blast tuyeres as conveniently can be employed. The position of the tuyere is most favorable when placed on both sides of the hearth. The tump is that part of the hearth† which is first burnt out ; and if the tuyere is in the back part of the hearth, the distance from it to the opposite tump is increased.

Water tuyeres are essential where the hot blast is used. The inventor and time of invention are subjects

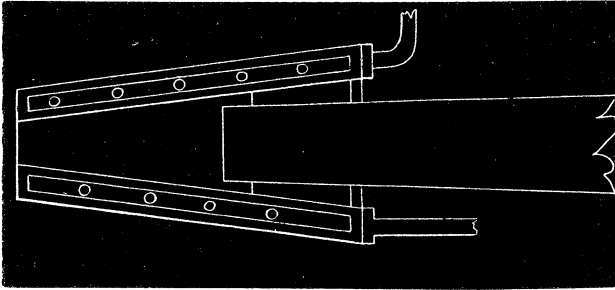
* *i. e.*, covered at the end with unmelted slag or cinder, and hence not showing the light when looked through.

† Or crucible, called in a general way the hearth.

of dispute. It was invented about the time of Neilson's discovery, and some think much before that time it was practically in use.

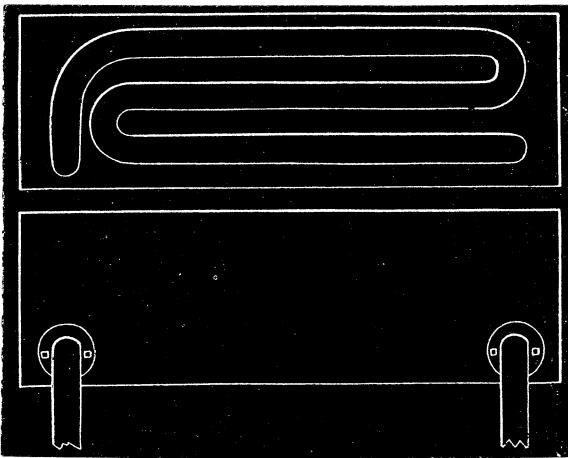
The Scotch tuyere, so called, consists of a wrought-iron tube, running through a cast-iron box of the following form—the tube running straight from the outer

Fig. 142.



side to the nose of the cast iron and returned outside in coils. The iron is cast around these coils. A water tympan is

Fig. 143.



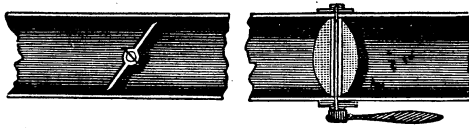
also used after this form. Some have proposed to dispense with the cast iron and surround the nozzle with a coil

alone—and others to use but half the length of cast iron—but the form most generally approved is that just described.

Valves.

[Valves are essential in blast conducting pipes; first, for shutting up the blast entirely; secondly, for diminishing and increasing it at pleasure. The first kind is needed where the blast is generated, for various purposes, by the same blast machine. The valves in use are the sliding, the conical, and the trundle. The first two are at present but little employed. If well made, the latter kind of valve is very useful. Fig. 144 shows a longitu-

Fig. 144.



Trundle-valve.

dinal section of a part of a pipe and a valve; *a* is a section through the axis of the valve, and *b* a view of the valve and a section of the pipe. Both ends of the axis run through the pipe. At one end it has a handle, and, in many instances, a graded scale, which indicates the amount of air which passes through the valve, or in other words, it shows the opening of the valve. At each tuyere or nozzle, a valve is sometimes placed, which serves either to shut off the blast entirely, or to regulate the passage of whatever amount is needed. At the nozzle valve, a scale is very useful, partly for the purpose of adjusting the blast, and partly for that of fastening the handle of the valve, and keeping it in a certain position.

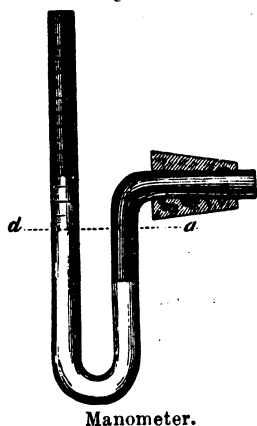
The laws which govern the construction of blast pipes, valves, and tuyeres, are summarily, as follows: The interior of the blast conductors should be as smooth as possible, for an uneven surface causes great friction.

The friction of the air is proportional to the length of the pipe, and to the density of the air which passes through it. It is proportional to the square of the speed of the air, and the reverse of the square of the diameter of the pipe. Obstructions caused by short bends in the pipes are inversely proportional to the angle of the bend, and are governed by the laws of hydrostatics. Sudden contractions and expansions of the pipe occasion a whirling disturbance in the current of the air—a loss of power, or, what is the same, of blast.

Manometer.

The pressure of blast necessary for different operations is an interesting question, and one undoubtedly of practical importance. If we know what is required, we ought to be enabled to judge to what extent we can succeed in accomplishing what we propose to ourselves. To measure the pressure of the blast, the surface of the safety-valve is generally resorted to—that is, observing the whole weight of the valve, and the area of opening it covers. This is a very imperfect way of coming to a knowledge of its true value; for, if the plate of the valve is much larger than the opening it covers, the real pressure of the blast may be but half of that which the safety-valve indicates. The real, active pressure must be found at the nozzles; and if we reflect upon the impediments which the blast receives in its passage to the tuyere, we shall have no doubt as to the necessity of measuring the pressure of blast at that point. The most simple form of a manometer, or measure of blast, is represented by Fig. 145; it is a glass tube of the size of a barometer tube, bent as shown in the figure. *a* is a cork stopper, which is pushed upon the tube; this fits in a hole bored into the blast pipe as near the nozzle as practicable. Such a manometer is easily made. A piece of glass tube can be obtained from almost any glassware store, the length of which, for a charcoal furnace, should be twelve inches, and for an anthracite fur-

Fig. 145.



nace, twenty-four inches. Such a glass tube can be heated to redness in a strong flame of alcohol, just at its centre, and the two ends bent round to form a siphon. The one leg may be heated to form the protection for the stopper. This tube is partly filled with mercury, which should reach sufficiently high above the lower bend, in inches, to equalize the pressure of the blast in pounds. An additional inch should be added to keep the mercury always in both legs of the tube. If the bend at *a* is connected with the blast pipe, and the compressed air is working upon the mercury, the latter will be pressed down in *a*, and rise in *d* proportionally to the density of the blast, or, as it may more clearly be expressed, proportionally to the difference between the density of the atmosphere and the density of the blast. The difference in inches in the height of the mercury between *a* and *d* amounts very nearly to the pressure of the blast in pounds, if we divide this difference by 2. From this it is evident that, as the mercury sinks as much in *a* as it rises in *d*, its height in *d*, above the level *a d*, which is the line of rest of the mercury, is, measured in inches, very nearly equal to a pound of pressure of the blast to each square inch. For practical purposes, this simple instrument may, by calling the height above *a d*, in inches, pounds of pressure, be deemed quite sufficient. A division of inches, and twelfths of inches, may be cut into the glass. The mercury should always be kept as high as *a d*. A perfectly plumb or perpendicular direction of the leg *d* is indispensable, if we wish to obtain accurate results. Where hot blast is used, the mercury would evaporate, by coming in contact with it. This evaporation may be prevented by putting the manometer to the end of a lead or iron pipe of an inch or less bore, and by putting this pipe, which conducts the blast from the main

pipe to the manometer, into a trough of cold water; the hot air will thus be cooled before it reaches the mercury.

Measurement of the pressure or density of the blast, whether for our own observations, or for comparison with those made at other establishments, is almost indispensable. It affords an opportunity both for observing imperfections in our own blast machines, and for obviating them. It shows the difference which exists between the densities of the blast of different establishments, which difference escapes common observation. Above all things, it draws our attention to the oscillations, or difference of density, caused by the machinery, and will assist us in correcting them. The density of the blast is no absolute measure, whether taken at the manometer or by any other means. This density is the difference between the density of the atmosphere and the pressure in the blast pipe. A given power at the blast machine will throw a greater amount of blast into the furnace when the mercury in the barometer is high than when it is low.

General Remarks on Blast Machines, &c.

It is generally admitted that no economy should be exhibited which, in any respect, interferes with the quality of machinery. If this be true in relation to every department of iron manufacture, it is particularly true with reference to the blast machines connected with the blast furnace. No expense ought to be considered, where the matter which concerns us is a blast machine. Though permitted to economize to an extent which would injure the utility of any other apparatus, yet so great is the importance of the blast machine, that our success is commensurate with the manner in which it works. The pressure of the blast ought to be at all times perfectly within the power of the manager of the furnace. For this purpose, a well-constructed machine, and a surplus of power, are indispensable. The oscillations of the pressure ought to be as slight as possible. It is almost impossible to make a uniform blast without

a receiver; for this reason, it is advisable to employ a regulator at every blast machine. The iron cylinder machine is undoubtedly preferable to all other blast machines. Anthracite, coke, and hard charcoal furnaces cannot be carried on to advantage without iron blast. In wooden cylinders, a pressure as high as five-eighths or three-quarters of a pound may be obtained; this is sufficient for forge fires, and blast furnaces where pine, or ill-charred leaf-wood charcoal is employed. Hard, sound charcoal, anthracite, and coke require a greater degree of pressure.

a. The effect of iron cylinder blast machines, compared with that of the motive power applied, is from 60 to 65 per cent.; of wooden cylinders, from 50 to 55; of the blacksmith's bellows, and wooden bellows of similar construction, from 30 to 40; and of all the fancy machines scarcely from 15 to 20 per cent. The Cagniardelle, or screw bellows, is, in this respect, superior to all, for its effect amounts to from 90 to 95 per cent. of the power applied.

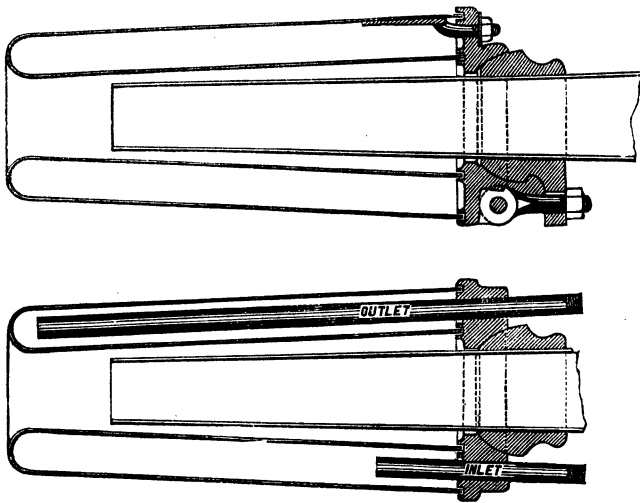
b. The location of the blast machine should be as near to the furnace as possible, with the object of avoiding long blast conductors. Too close proximity to the furnace is as bad as too great a distance from it, for the air around the furnace is always warm, and consequently is rare and contains considerable moisture. A cool, dry place, to which no moisture has access, and which is free from sand and dust, is, of all locations, the best. The air contiguous to a furnace is always impregnated with sand or dust, which will be drawn into the blast cylinders, and injure the machinery. We ought to be very cautious in selecting the locality of fans; otherwise a considerable loss of power ensues. The pressure, or blast, in a fan is produced by centrifugal force; and as the specific gravity of the air augments in some measure the effect produced, it is evident that the air passing through it ought to be as cold, or heavy, as possible.

The importance of good blast machines, and of the application of as strong a pressure as the fuel will bear, will be still more apparent, if we reflect that the degree

of heat depends, to a great extent, on the draught, and that the blast is the artificial draught. As the highest heat is, in almost every case, most favorable to the amount of fuel consumed, it is evident that, if no other advantage accompanies the strongest pressure, that of economizing fuel must result from it. As a general rule, we may say that a comparatively small quantity of dense blast will be productive of as high a heat as a much larger quantity of weak blast. Therefore, pressure is an equivalent for hot blast.]

We will only add to the above, that a new form of tuyere has been invented, which in some quarters has given satisfaction but has not yet been so extensively introduced as to have a reputation. It seems, however, to have some merits, as we should expect that it should possess, being the invention of a practical man. The following description has been sent us by one who has seen it tried. The tuyere is Player's patent, Fig. 146.

Fig. 146.



Player's tuyere.

This improvement is said to effect a great saving of time, the loss of which, by the use of the ordinary kind, is caused by the blast furnace having to remain inactive

during the operation of removing a leaky tuyere. This loss often amounts to two or three hours, and the time, alone, is supposed, in some cases, to be worth, on the average, \$100 for each stoppage, independent of the cost of a new tuyere. Moreover, the new tuyere can be applied in a quarter of an hour; there is no liability of this tuyere burning out, as the water must flow around the nose of the tuyere before it escapes. There is also an improvement in fixing the nozzle in its place in the centre of the tuyere by means of a ball-and-socket joint instead of the usual method of ramming clay and bricks between the tuyere and nozzle to keep the latter in its place and prevent the escape of blast. The back end of the tuyere can be used over and over again, whereas tuyeres of the usual construction are altogether useless is soon as a small leak occurs.

The tuyere is made in two parts, fixed together by screws, allowing it to be opened and cleaned out should any sediment or scales have accumulated in it. The fore part of the tuyere is made of copper, about an eighth of an inch thick, composed of two cylinders braced together near the nose, leaving an annular space between them of about two inches wide. The open end of this annular space is closed by a cover of cast iron; this is fastened to the copper cylinders by means of bolts and nuts. In the cover are placed rubber rings to make the joint water-tight. Through the cover are fixed two pipes, to carry water in and out of it. This arrangement causes a thorough circulation of the water through the tuyere and at the point where it is most wanted at the nozzle.

CHAPTER XII.

HOISTS, GENERAL EXPENSES, MISCELLANEOUS DETAILS.

THIS term is used to express that machinery, as a whole, whose duty it is to raise the charges of the fur-

nance to the level of the tunnel head. Considerable ingenuity has been expended upon the Hoist.

1. *Hoists on Inclined Planes.*—The simplest is that method whereby the charges are raised as logs are raised at some saw mills. The tunnel head is connected with the ground by inclined planes, sustaining tramways, or rails, upon which the charges, in cars, are drawn by chains or ropes. These need no further description. They are used at Barrow-in-Furness, England, and in Centre Co., and elsewhere, in Pennsylvania.

2. *Water Hoists.*—These depend upon the gravitation of water, or water weights, and not what is technically called hydraulic pressure. High vertical frames, somewhat similar to those we have illustrated below, for air, are erected, and the floors of the barrow-platforms upon which the barrows are run, when about to be raised, are made capable of holding water. They are connected with a chain, or rope, run over a suitable grooved wheel acting as a large pulley-wheel at the top of the frame. When one platform is down and loaded, water introduced into the other at the top, overbalances the loaded platform below and raises it to the tunnel head. The ejection of the water by opening a valve, together with filling the other box platform, causes the already descended platform to rise while the other correspondingly descends. This method requires a constant supply of water, either from a natural, or artificial, higher source. In some works a stand-pipe is kept constantly filled by a pump, and serves the end desired. Such an arrangement may be seen on the Lehigh at several places above Easton, Pa., as for instance, at the Crane Iron Works, where it was used from the beginning. This is also an English method, used at Langloan and Gartsherrie.

Armstrong's Hydraulic Hoists.—At the works of the Rosedale Iron Company the materials for the supply of the smelting furnaces are raised by hydraulic hoists, arranged on Sir William Armstrong's plan, each hoist having duplicate lifting cradles which rise and fall alternately. One of these double hoists has a lift of 103

feet, and the other a lift of 80 feet. In each of the hoists the rams by which the lifting chains are worked have a stroke equal to one-tenth the total lift, each chain passing over a four-sheave block fixed to the frame of the hoist, and a five-sheave block carried at the head of the corresponding ram.

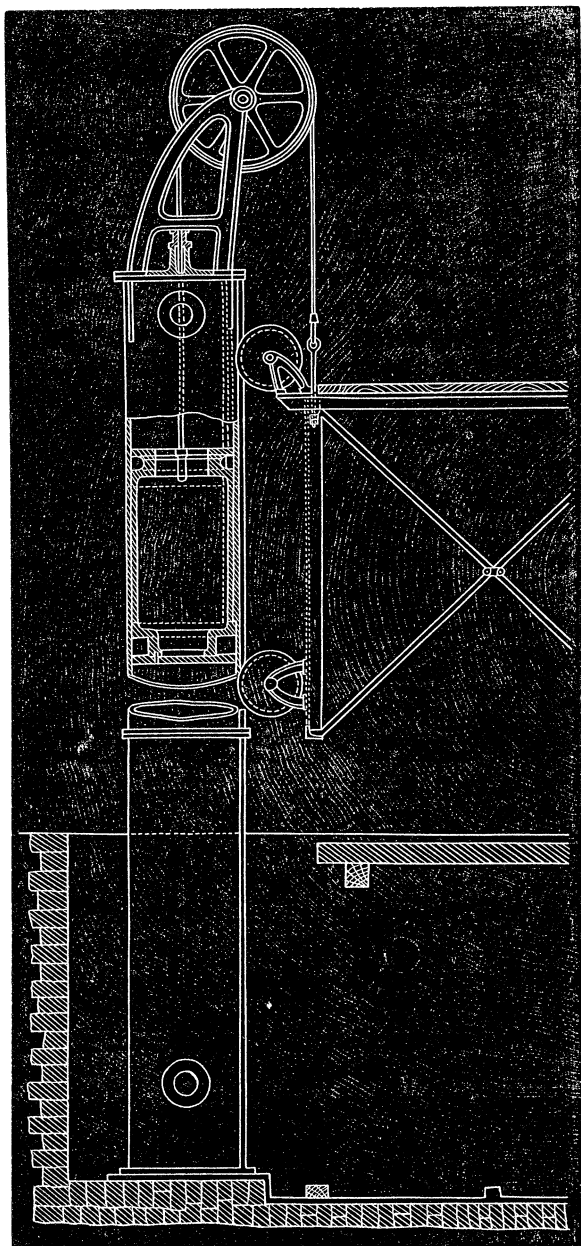
From the five-sheave block carried by the head of each ram the chain worked by that ram passes over a grooved pulley about 6 feet 3 inches in diameter, carried by bearings at the top of the main framing, this chain being of such a length that when one cradle is at the bottom the other is at the top of its lift. The two cradles thus balance each other, and the strain thrown alternately upon each of the lifting chains is merely that due to the load taken up and the power required to overcome the friction of the apparatus.

Each cradle consists of an iron and wooden floor connected by side frames of iron with a transverse iron beam to which the chains are coupled; and each cradle is furnished with guide pieces working in guides supported by the main frames. These main frames consist of six cast-iron columns, and are connected together by wrought bracing, and by wrought-iron plate girders at the top. The water for working the apparatus is employed at a pressure of 700 lbs. per square inch, and the supply is furnished by a pair of small engines working the pumps direct from the piston rod. The pumps deliver the water into a pair of accumulators, each having a stroke of 15 feet, and being loaded with a weight of 35 tons. The valve gear of the hoists is arranged so that the latter can be worked either from the galleries or from the ground level, and a self-acting stop motion is provided, so that the cradles are brought quickly to rest at the end of their strokes, but without shock or jar. The whole arrangement is said to perform its work extremely well, and to give great satisfaction.*

Air Hoist.—A much more complete, and a cleaner method is that adopted at other works in the same Le-

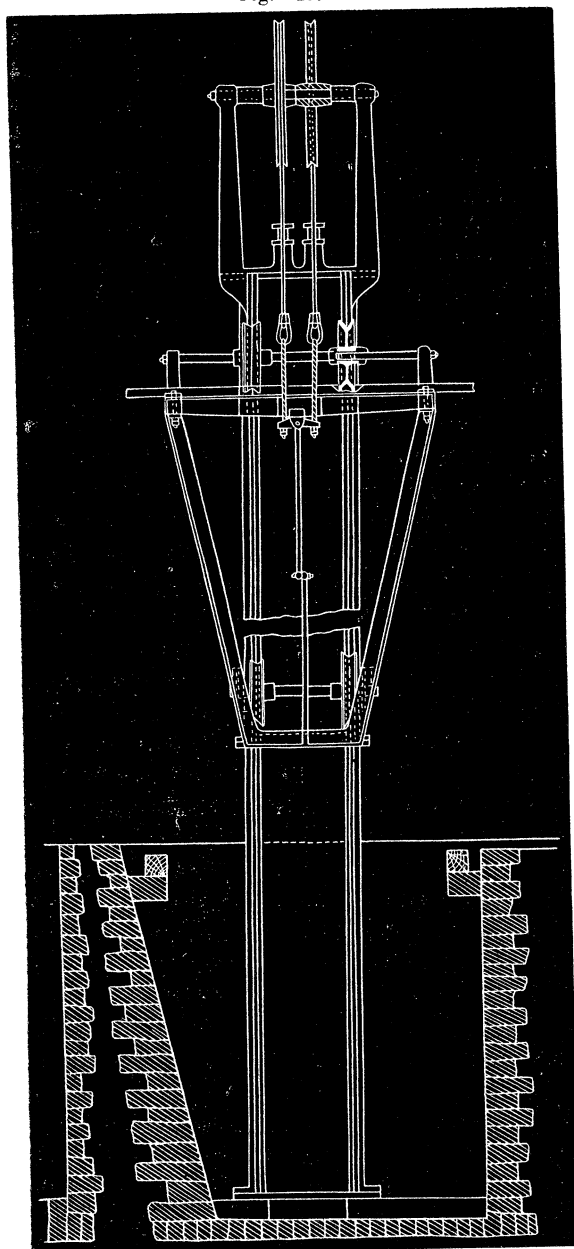
* Engineering, March 1, 1867, p. 202.

Fig. 147



Air hoist, Saucon works, Pa.

Fig. 148.



Air hoist, Saucon works, Pa.

high region, at Saucon Iron Works, Thomas Works, Pa., and in other States, called the blast, or air hoist, wherein the blast pressure is introduced into vertical pipes. The preceding drawing will sufficiently illustrate the plan. Vertically a little over one-half is represented, the other half being precisely similar. The tube is cast in sections, bored out and fitted. The guide wheels run on guide rails, the air is introduced below and above as needed for raising or lowering the platform. Fig. 147 presents the side view of Fig. 148.

Air Engine Hoist.—A very complete plan is in operation at Glendon Iron Works, above Easton, Pa. On the level of the tunnel head is a small engine, driven by the blast from the blast cylinder. The link or reversing motion is similar to that of the locomotive. The gearing of the engine is simply upon spur wheels which steadily and rapidly raise the charges. The only objection made against it is that of the noise made by the exhausting air, which did not seem to us materially greater than in the usual form of the air hoist. It works very satisfactorily.

Steam Hoist.—At several furnaces we have the steam acting directly upon a chain which turns a drum-pulley, and so multiplying the distance through which the platform is raised, that one stroke of the steam cylinder is sufficient to raise or lower the platform its whole distance. This plan is used only where the lift is not for a great height.

At Johnstown, Cambria County, Pa., Bloomsburg, Pa., and at some other places, furnaces have been erected near a hill and the main roads run on a level with the tunnel head. Advantage is taken of this position so that there are no hoists needed.

Economies of Furnace Practice.

Methods in Erection.—In the last three years some unusual accidents have occurred in the erection of furnaces. We have examined the causes in several of

these cases and have found that they have been attributable to the following defects and oversights. 1. Insecure foundations. Some engineers are not practically aware of the exceeding weight and pressure of furnaces and hoists. Some of these structures require a small area of base with comparatively enormous superincumbent weight. Under some circumstances we might make no distinction between pressure and weight, but, we think it is a true distinction in this case. By weight we mean that force of gravity applied at that juncture where the general homogeneousness of material terminates; and by pressure, the same force as applied in the general structure of material itself. Allowing this definition, we would say that the weight of some furnaces, of even moderate size, creates a pressure upon foundations of a formidable amount. It is not therefore strange, that, with the addition of material of the charges, cracks and injuries occur after, if not before, the blowing in. We have seen some furnace and hoist-walls give way before they were quite complete. For illustration sake, let us suppose we weigh a furnace of 50 feet height and 20 feet bosh, built of limestone and put up in the usual way. As the stack will be filled with material whose average density will fully equal that of limestone, or other rock used for this purpose, we may consider its specific gravity 2.7, water being 1. Taking the latter at 60 lbs. per cubic foot, we shall have a fair data to begin with. Supposing the above furnace to be only 20 feet square, on the average, to level of tunnel head, and the weight of each cubic foot at 162 lbs., we can obtain the reasonable average weight of all. These elements then would give a weight of 1446 tons and the ground (if not built on rock) would receive, if all things were uniform, a pressure of about 56 lbs. upon the square inch. It will readily be seen, therefore, how easily a hoist, or furnace-stack, may be injured by the yielding of even a part of the foundation, causing, as we have seen in more than one instance, a cracked wall, before any fire was kindled within the works. We were informed by a gentleman who had more than fifty years

of experience in building, that small stones, laid in the trench excavated for walls, were more secure, as a first layer, than large stones put down first, and we were referred to a large and heavy stone structure, erected more than twenty years before, upon such a foundation, and in which heavy machinery had been running since its erection with not a crack of any kind apparent. We saw the walls of this building after they had been subjected to a very severe fire, but no crack made its appearance, giving additional evidence that there was no weakness in the foundation. There is much practical philosophy, unusual as the recommendation may seem, in laying small stones down first and letting them run into the ground, conformably to the under surface of the large foundation stones used in furnace constructions, and in their accompanying walls and hoists. 2. Improper building material. We have seen several illustrations of unwise economy in this respect, so far as furnace works are concerned. In all these cases the stack and hoists became useless after being nearly completed, because of the use of a friable sandstone, taken from near at hand, to save hauling from a distance. The pressure was too great for the stone. Materials are improper where the individual stones are small, especially at the corners of the structure, and they should decrease in ascending, as a matter of preference, however, and not of necessity. It is a mistake to suppose that all limestones are unfit for furnaces. Some siliceous stones of this nature answer admirably when protected from fire. The conglomerates, consisting of quartz pebbles, cemented with aluminous silicates, form an excellent material where the adhesiveness is sufficiently great. The conglomerates of the anthracite and other coal regions form excellent hearthstones, and have been used most efficiently for many years as some sandstones have been also; the composing pebbles vary from large stones to smallest pebbles, and there is no difficulty in obtaining large masses. In some places fire-clay bricks of large size have been used for hearthstones with satisfactory results. Kaolin mortar, containing soda and lime, we

have good reason to suspect, is inferior. The same may be said of fire-bricks made from such material. Good kaolin mortar is generally fine in texture, with little grit, and hardens soon and, when dry, the mortar will not rub off in gritty particles. In putting up several furnaces we have had a fair trial made of kaolin clays, or fire-clay cements, and have found, thus far, that the clays containing no lime or soda and partaking of the nature of silicate of alumina only, appeared to set more firmly, as mortar, and remain uninjured longer, as bricks. The lime-kaolins are affected by fire comparatively more rapidly than others. Nothing but an analysis can detect the lime and soda, although we have seen some powdery kaolins which were lime-kaolins, and we have suspected that this peculiarity might owe its origin to the presence of lime, or soda. But when properly mixed and subjected to strong heat in a smith's fire, these kaolins are easily tested.

Positions of Furnaces.—Great care should be taken in choosing the site of a furnace to allow of ample room for getting rid of the slags. Some furnaces have been so placed that great expense has been indirectly incurred in this respect. Some companies with which we are acquainted will, in less than five years, have to expend a sum of money, in removing slag, which will equal all the profits for a year or two, but which might have been saved by a proper location at first. Others have been erected near the foot of a hill in a location constantly subjected to overflow after every rain, and resulting in a wretched state of road in summer, and in much troublesome ice in winter. Another has been located so near a creek that it is within and below the high water mark of freshets which have more than once caused much trouble from a chilled hearth and overflowed cast-house. The above remarks are sufficiently suggestive upon this subject.

Scaffolding and Dropping.—The former is a term applied to that condition wherein the charge ceases to come down, and where no more can be put in at the tunnel head. *Dropping* or jumping is the term used

when the charge having for a time "hung" on the sides, suddenly falls; a flame then issues to a greater height than usual, and the furnace-charges may proceed to melt, and perhaps go down as usual. Various causes may produce scaffolding, indirectly. One most troublesome *immediate* cause is the pasty condition of the metal, and that is immediately due to the formation of malleable iron, which, requiring a greatly increased temperature than cast iron in the melting, refuses to release the other ingredients, or components of the charge, and an arch is formed in the furnace. Unless it be immediately broken down, or melted down, it becomes cooled, and the mass is set beyond all cure; the furnace must now be blown out and all the delay, loss of iron, trouble and expense of unloading, and relining are now to be incurred because of this catastrophe. *The signs* may sometimes be suspected by the "scouring" cinders, that is, the dark, viscid, irregular, and otherwise altered and unusual hot slag. It may be suspected by the ceasing of the charges to sink regularly, and by the diminished flow of cinders or by all these signs combined. *The remedy* may be found in dropping heavy weights into the tunnel head, directed from temporary derricks "slung" together over the tunnel head with tackle and block, thus allowing the weight to be drawn up and dropped down. This has frequently succeeded. Again, some have remedied the difficulty by "scouring" the furnace, as they have called it, by the introduction of a small amount of steam into the hot blast, at an early stage of the difficulty. This has worked well in one of our largest furnaces. A pretty bad case of scaffolding was remedied at Scranton, Pa., by the rather hazardous experiment of introducing, in a wet blanket, a keg of gunpowder through the tuyere opening; it was, however, successful.

Another kind of scaffolding, more easy to remedy, is that resulting from the mechanical cause of accidental fitting and arching of large pieces or masses in those furnaces of the cylindrical and inclined boshes. The drop-weight will almost always remedy this kind of

scaffolding. The *prevention* is found in charging smaller masses and in more regular distribution.

Causes and Occasions.—Among the causes are supposed to be sulphur and zinc in the ores and coals—more probably it is in bad filling and using irregular masses of undue size, especially as regards the coal. The occasion most favourable to scaffolding, seems to be, a high degree of temperature in the hot blast combined with high pressure of blast. We have noticed, repeatedly, that where these two elements were low, the furnaces were rarely if ever troubled with scaffoldings, or dropping. While, therefore, we would not assert these elements to be *causes*, they doubtless promote scaffolding by furnishing the most favorable *occasion*.

Stopping the Blast.—How long may a furnace remain in healthful condition after all blast has been discontinued? This question should be answered in reference, first, to our anthracite furnaces as the difficulty of discontinuing blast is more apparent in them than elsewhere. It is, comparatively, but lately that the attempt has been deliberately made of keeping an anthracite furnace in running order with blast arrested for any length of time. Some years ago an explosion of gas took place at Scranton, Pa., disabling the engine-house to such an extent that the engines had to be stopped. The tuyeres were removed and the holes stopped thoroughly with clay, and not till after sixty hours was the blast turned on. The fore-hearth had to be cleared of some cold cinder, but the furnace proceeded to work and the casts were made as usual without further difficulty. The fact was of course considered unusual. Some time after this, at the same iron works, an occasion for stopping presented itself, and the same antecedent precautions were taken. The furnace was allowed to stand entirely without blast for twenty-four hours. We were told by the superintendent, that the furnace appeared actually to work better. A second occasion for stopping presenting itself with the same general results, but after some hours the cinders seemed to indicate a slightly irregular action in the furnace, which, however, might not have been due to any arrest of blast as characteristic

of such an arrest as the same difficulty frequently occurred in the same furnace before the experiment had been made in any way.

The most remarkable stoppage of blast, however, occurred at the Irondale anthracite furnace at Bloomsburg, Pa., Chas. R. Paxton, Pres. The blast engine suddenly broke its crank. A new one had to be cast and turned out in Philadelphia, sent to the works and fitted. This work occupied several days. The following is the account. Engine broke six o'clock P. M., April 17th, 1867—tuyeres stopped up as above—tunnel-head left open—107 hours elapsed and blast turned on, and the following is the record of the working with the first cast after the blast had been turned on.

	Charges.	Tons iron cast.
Six o'clock A. M., April 24,	4	12
" " " 25,	25	14
" " " 26,	24	11½

The next casts were more uniform, and the furnace has been running regularly ever since without scaffolding or trouble. The irons are forge irons in both of the above mentioned furnaces. Mr. Paxton has exhibited much thought with successful experiment, in determining the conditions upon which a furnace may remain in order without blast for considerable time, and we shall refer to his experience and skill on this subject again.

The instances thus far, with slight exception, were those of blast arrested without a minute's warning, and consequently without preparation. Such satisfactory results have not occurred, however, in every instance. At Danville, Pa., one furnace, Hancock & Crevelling, proprietors, chilled in eight hours after stopping, and it becomes, therefore, a question of great interest, *What constitutes the difference?* We have during the past year, or for a longer time, made considerable effort to obtain a satisfactory answer to this question, with considerable success in some cases and very decided success in others. The most satisfactory illustration of the method and of the proper precautions to be adopted before stopping an anthracite blast-furnace, we have seen at Bethlehem, Pa.,

at No. 3, or Northampton Furnace, under the general superintendence of Mr. Fritz, Mr. Enoch Phillips being the founder. At this furnace it was necessary to put a new cut off to the engine, and, some days before stopping, preparations were made for this purpose. The furnace is about one year old—of stone—six tuyeres (two of them two and a half in. nozzles, four of them three in. nozzles), pressure five lbs. to the inch, heat (as indicated by the pyrometer at the time we were there, after the blast had been blown in some time) 650° , although it was asserted to have been much higher. Sixty hours before stopping, the burden of ore (mixed magnetic and brown hematite) was reduced slightly, the coal increased, otherwise the charges were unaltered, the iron made at the time of stopping being nearly, if not quite, No. 1 foundry. Just before stopping, the nozzles were removed—tuyeres stopped with clay—tunnel-head left open, as usual, the water in the tuyeres and tymp reduced to one-third, or less quantity, and the engine stopped from Monday night, eleven o'clock (no blast whatever being turned on) till Wednesday night, twelve o'clock. A very few minutes of cleaning forehearth was required, and the first cast was a beautifully uniform and crystalline foundry iron of a high order of No. 1 foundry. We personally examined the iron, only six tons of which came down during the forty-seven hours of rest. It was thought by some that any attempt at such a stoppage at this furnace would be a failure from the fact that a Lurmann's front had been put in and was in use at the time, but Mr. Phillips assured us that he had no doubt that the proper preparation of the furnace was all that was essential.

There can be but little doubt that the fact, which we have fully corroborated, that for some time after the stoppage of a furnace, properly prepared, the iron is largely freed from sulphur, shows that the roasting process or volatilization of hurtful substances is progressing quite favorably, and this would seem to commend to our notice the higher stacks if but for this purpose and result alone, namely, the elimination of sulphur, arsenic,

water or any other hurtful or otherwise unwelcome ingredient which might, by this condition of long continued heat, be evolved.

In the above mentioned furnace there is a Player's hot-blast stove of sixty pipes, but we consider this of no importance in influencing the results.

As we have before intimated, some special practical attention has been paid to this subject by Mr. Paxton, and, after a series of experiments, we have received the following epitome from the founder of the company's works: Any anthracite furnace thoroughly heated, that is, one which has been running long enough to be perfectly dry and warm, properly builded, may be stopped under the following preparations and conditions. The furnace must be put into condition of light ore burden, or, rather, heavier (than usual) coal burden, so that it may have the benefit of the extra per cent. of carbon to allow of quietude, that is, a quiet combustion. Coal must be supplied so that the charge shall have an abundance or a sufficiency to supply the consumption-demand during the time of suspension. The duration of this time must be determined by the size of hearth, the diameter of the furnace, the height of furnace, and the openness of the ore, and excellence of the limestone, and, indeed, in this order as to importance, the first mentioned circumstance being most important. But in general, no well-built furnace properly managed and properly prepared, should suffer from twenty to forty hours' arrest of blast, but after a very little working of fore-hearth, should begin as usual and with a somewhat improved quality of ore from roasting, and should continue to run out at least as good foundry iron if not as good forge as was running antecedently to the arrest of blast.

In addition to the above remarks, we may add that some stoppages which are extreme in our opinion, may have taken place under circumstances with which we are not acquainted, but one intelligent and very successful furnace master, Mr. Josiah Ralston, of Bloomsburg, Pa., informs us that the longest period he ever knew, personally, of stopping, was ten days. That was, indeed,

the longest time he ever heard of, except that his father and others from the old country spoke of four or five weeks' closing. In his own case there was no trouble in the working of the furnace after ten days' stoppage except, that, because of a long fore-heath, they had to chop out a little. But in making stops of longer duration than twenty-four hours the furnace (as we have shown above) must be in a particular condition. In the last mentioned case of ten days, it required two hours to close up. At the last-mentioned furnace they stop thirty-six or forty-hours, two or three times a year for fixing blast pipes, &c. Mr. Ralston says, that he has never experienced any difficulty, and for such short stoppages, as last stated (twenty-four or thirty-eight hours), he requires only fifteen minutes to close up, but a furnace must be put into condition which may be seen by the cinder, for if too rich in iron it may probably chill whilst the furnace prepared for the stopping, never will chill. Where therefore, every associated circumstance is in skilfully prepared condition, the furnace master may arrest the blast, make his repairs for twenty, thirty, or sixty hours, and proceed as usual without fear of evil results, as has been abundantly tested.

As for the *stoppage of coke furnaces*, there seems to be much less difficulty. Indeed it is now quite common in Great Britain, as we understand, and it has been so for years, to close up a furnace and stop for some time without any difficulty until repairs can be made which may require one, two, or three days. The same has been done in this country and is at present frequently attempted and successfully. Mr. Crowther, of Alleghany City, Pa., and several in Huntingdon County, Pa., have succeeded in the same experiment, and with similar success in late years. The precautions above stated should be taken, but they do not appear at all times so necessary in these furnaces. Coke and charcoal retain heat under very much altered conditions compared with those which affect anthracite—the only difficulty hitherto experienced has been associated with anthracite as a fuel.

Cost of Erecting Furnaces.—This varies so much in various places, even though identically the same plan of furnaces is adopted, that it will be impossible to arrive at any one estimate which will serve all places. The following, however, will give some idea of estimates, both of stone and of boiler iron furnaces.

In and around Philadelphia, Lake Champlain, Pittsburgh, St. Louis and Marquette, we shall find, in some respects, as many prices as there are places, and indeed in the boiler plate of furnaces not twenty miles from each other, upon the Lehigh, we have found that one master paid $8\frac{1}{4}$ cents per pound, and another $6\frac{1}{2}$. We shall speak at present, however, of stone furnaces. At this point we would say that even in the same county one location may cause more cost than another, and so many circumstances may modify that it is very unsafe, without visitation to, and examination of, many furnaces, to pass judgment as to that which is most economical.

One of the very latest and skilfully erected furnaces has been put up under the engineering skill of Mr. Ed. N. Kirk Talcott, a gentleman of thoroughly acknowledged ability in this line, to whose personal care we are indebted in preparing the following specifications and estimates of a stone anthracite blast furnace at Dover, New Jersey. It must be borne in mind that all the estimates are made at this spring (1869) prices. This furnace has been considered unsurpassed in its proportions, strength, and general appliances, by any in the country.

Stack.

51 feet square at base; 47 feet on top of stone work; stone masonry, 45 feet high. Total height, 60 feet; bosh, 16 feet.

Stone masonry	28,000	
✓ Lining, hearth, gas chamber, &c.	19,500	
Excavation	500	
Castings, tie-rods, &c.	7,500	
	<hr/>	55,500

Engine and Boilers.

Engine, horizontal; steam cylinder, 40 inches in diameter; blowing cylinder, 90 inches in diameter; stroke, 84 inches; 6 cylinder boilers, 60 feet long, 36 inches in diameter; 4 under boilers, 24 inches in diameter, 48 feet long.

Engine and boilers complete . . .	26,100	
Setting up engine . . .	3,000	
Masonry to support boilers . . .	13,700	
Brickwork for boilers . . .	3,000	
Boiler smoke stack . . .	1,800	
	<hr/>	47,600

Hot Blast Oven.

Thomas's patent, 60 pipes, set on the ground.

Castings	20,000	
Brickwork	3,000	
Smoke stack	1,500	
Connection and blast pipes, &c. . .	1,500	
	<hr/>	26,000

Engine House.

Of brick, 90 feet x 25 feet.

Walls	2,700	
Foundations	500	
Lumber	500	
Carpenter work	300	
Roof	350	
	<hr/>	4,350

Casting House.

51 feet x 75 feet cast iron frame.

Foundations	500	
Castings	1,200	
Lumber, car, work and roof . . .	1,700	
	<hr/>	3,400

Stock House.

50 feet x 150 feet. Three railroad tracks.

Excavation	500	
Masonry	1,700	
Lumber	4,000	
Carpenter work	1,000	
Railroad iron	800	
Roof	1,000	
	<hr/>	9,000

Elevator.

Double platforms 8 feet square, to lift 60 feet.

Lumber and framing	750	
Hoisting engine	1,200	
Wire ropes, gearing, &c.	1,050	
		<hr/>
		3,000

Railroad Tracks.

About fourteen hundred feet long.

Iron spikes, &c.	3,500	
Trestling	4,000	
Labor, &c.	1,000	
		<hr/>
		8,500

Reservoir.

Including storage reservoir of 150,000 gallons capacity—one-half mile of water pipe connection with canal for water supply and stand pipe 90 feet high at the works

Carpenter and blacksmith shops	7,500	
	600	

Employees' Houses.

Including four double houses, one large boarding house and house for Superintendent

Office	16,500	
	2,300	

Scales.

One ten-ton office scale, one seventy-ton railroad scale, three stock house scales

	2,500	
		<hr/>
		\$186,750
Stack	55,500	
Engine and boilers	47,600	
Hot blast oven	26,000	
Engine house	4,350	
Casting house	3,400	
Stock house	9,000	
Elevator	3,000	
Railroad tracks	8,500	
Reservoir	7,500	
Shops	600	
Houses	16,500	
Office	2,300	
Scales	2,500	
		<hr/>
		\$186,750

As explanatory of the above, in some particulars, Mr. Talcott writes us as follows:—

There are some features about our work here which have increased the cost quite materially, which might be avoided in some other locations. We were obliged to go about 12 feet below surface for our foundation, thus putting something over \$5000 away under ground. Our stack, you will notice, is a very large one, 51 feet at the bottom and 47 feet on top. It was built so purposely, in order to save fuel by avoiding the wasting of heat through the stack by radiation. I made some interesting experiments upon this point a year or more since and found my theory, that a great deal of heat was wasted by radiation, fully borne out in practice. This unusual size of the stack, of course, increases the cost of construction materially. Our furnace is 60 feet high, which is 5 feet higher than it is usual to build on the Lehigh. Our lining, too, is a heavy one, being 40 inches main lining and 8 inches back lining.

The location of our furnace is such that it requires a large expenditure to provide water for the use of the furnace. Situated on low ground we are obliged to pump all our water to a reservoir on a hill nearly half a mile from the works, thus necessitating a long line of pipe and somewhat extensive pumping arrangements.

Our engine is a horizontal engine, built by the West Point Foundry at Coldspring, New York, with steam and blowing piston, both on the same rod, both passing through both ends of the cylinders. I consider it the weak point of our works. It was, however, purchased before I was connected with the Company, and I have been unable to persuade our people to change it. I do not believe the style of the engine is a good one. My preference is decidedly in favor of a beam engine for blast furnace purposes.

Our furnace being about level with the railroad track, in front of us, we are obliged to secure dumping ground by building a long line of trestle work from the railroad to the stock house. This is an expenditure which might be avoided in a different location.

The following is an estimate of a cupola furnace, that is, a furnace with iron shell set upon columns with a mantle upon the columns, in the way illustrated in the Figure of the Saucon Iron Works, Hellertown, Pa., which we have given in a previous page (328.) This furnace is one of 45 feet height, 16 feet bosh. It is a good, substantial furnace. The wages for the stone work were as follows: Mason work, \$2 per perch, and when all materials are found, \$4 25 per perch. For these estimates we are indebted to Benjamin Crowther, Esq., of Alleghany City, who, as we are informed by Mr. Horton, of Rochester City, put up nearly, if not quite, the very first iron column furnace, with mantle, in this country after the suggestion and invention of the last named gentleman. The estimates are made for the region in and near Pittsburg, and are as follows:—

Engine	\$10,000
Air receiver and connections	3,000
Boilers " "	10,000
Pumping engine "	3,000
Furnace (including lining and hearth and all complete)	11,000
Hot blast and connections to furnace	10,000
Hoister (with water tanks, cisterns and pipes)	8,000
Engine house, brick and foundation	3,000
Brick casting house, with iron roof	5,000
Wood, stock " " shingle roof	4,000
Boiler " " iron "	1,000
Blacksmith shops and tools	1,000
Office and weigh scales	1,000
	<hr/>
	\$70,000

Before closing these remarks, we would recommend any one desiring to become acquainted with the simplest methods, and the most unpretending of stone blast furnaces in the United States, and wishing to study economy upon the scale of years long gone by, and be able to appreciate and comprehend the vast progress during the past fifty years, we would recommend such to visit the charcoal furnaces of Centre County, Pennsylvania, some of which, however, have been blown out for years past, having run

out of ore and fuel, for they have deforested the land for miles around, and now have probably "blown their last blast," but they will remain not only as curiosities, but several as sources of profit. We believe that some of the most ancient may be found along the line of the Lock Haven and Tyrone Railroad, of Pennsylvania. Some of the best charcoal iron in the country, however, is made in the most primitive manner at the Washington, Pennsylvania, and Logan Iron Works. We speak from personal knowledge of the Logan works. At the latter we have seen the old fashion wooden cylinders still in use and doing excellent service (June, 1869). The tympan is simply a plain plate of iron let down upon the fore hearth, which is entirely uncovered, the cinder running over whenever it gets high enough, and chooses to make its short journey down the embankment which covers the tapping hole, and which is dug into when casting time has come. The iron is tapped out through a hole in a plain dam, and the hole filled up again with sand and covered over with soil and sand mixed. Water power, only from a large spring or small collection of springs, is used. The blast is from $\frac{1}{2}$ to $\frac{3}{4}$ lbs. per inch. The casts are made in iron moulds at the rate of three in twenty-four hours, two tons each time, but the iron is deservedly of excellent character, and the furnace, while of the very simplest and most primitive construction, has paid abundantly, which may also be said of some of the others in the same region, but which may not be said of some which have cost ten times as much in other parts of the land. It may be seen from these remarks that the item of cost, in erection of furnaces, may have a very wide margin.

Calculations upon the Sizes of Furnaces and Blasts.—We have but little confidence in the practical value of abstract formulas for the purpose of deciding upon the size of a furnace or blast unless the ores, limestones, and fuel are regarded. We shall give the following formula as the most complete of its kind we know of, and although suited entirely to continental furnaces, it may be

adapted to our own. We are indebted to Crookes and Rohrig's edition of Kerl's Metallurgy for the following:—

Lindauer's Formula.—Finding that two preceding modes of calculation did not give mathematically exact results, since in the first modes the conditions influencing the dimensions of blast furnaces were too general, and the second mode, taking into consideration nothing but the quantity of blast, Lindauer investigated those elements required for a more perfect solution of the present question, and deduced the following formulas:—

For charcoal furnaces,

$$D = 0.8448 \sqrt[3]{\left[\frac{k}{100 y'} + \frac{100 + c}{q' y} \right] \frac{Z}{24} E}.$$

For coke furnaces,

$$D = 0.8883 \sqrt[3]{\left[\frac{k}{100 y'} + \frac{100 + c}{q' y} \right] \frac{Z}{24} E}.$$

For coal furnaces,

$$D = 0.9728 \sqrt[3]{\left[\frac{k}{100 y'} + \frac{100 + c}{q' y} \right] \frac{Z}{24} E}.$$

In these formulæ the letters have the following value, and the figures give the average obtained in practice:—

D = diameter of the belly in Austrian feet (1.037 Eng.).

E = the production of pig-iron in 24 hours in Austrian pounds.*

Z = the time which one charge requires to pass the furnace. For charcoal, 16; for coke, 40; and for coal, 48 hours, when producing gray pig iron. Three-quarters of the time are required when producing white pig-iron either with charcoal or with coke.

k = consumption of fuel per 100 lbs. of pig-iron, namely:—

	With cold blast.	With hot blast.
Charcoal	160	130
Coke	280	213
Coal	330	250

c = the addition of limestone to 100 lbs. of ore mixture, 15 lbs. on an average when using charcoal, and 35 lbs. when using coke and coal.

y = weight of 1 cubic foot of mixture, on an average, 90 lbs. with ores yielding from 20 to 40 per cent. of iron.

* 8639 grs. Troy, 1 lb. Avoird. being 7000.

y' = weight of 1 cubic foot of fuel, 7 lbs. for soft charcoal, 12 lbs. for hard charcoal, 20 lbs. for coke, and 40 lbs. Austrian for coal; the weight of the mixed fuel is obtained by calculation.

q' = average amount of iron contained in the mixed ores after deducting the loss in smelting.

Upon transposing the average values of Z , c , k , y , and y' in the above formulæ, the following diameters for the absolute productions and for the different kinds of fuel will result:—

	For cold blast.	For hot blast.
For soft charcoal,	$D = 0.4766 \sqrt[3]{E}$	$0.4500 \sqrt[3]{E}$
“ hard “	$D = 0.4125 \sqrt[3]{E}$	$0.3920 \sqrt[3]{E}$
“ “ “	$D = 0.6054 \sqrt[3]{E}$	$0.5657 \sqrt[3]{E}$
“ “ “	$D = 0.6249 \sqrt[3]{E}$	$0.5917 \sqrt[3]{E}$

Differences which may be noticed by calculating the diameter of the belly of blast furnaces, may be caused by employing an unusual quantity or pressure of the blast, thus altering the time in which a charge passes through the furnace, or the ores may be so good as to greatly facilitate the production of gray pig.

When employing mixed fuel, a particular formula must be deduced.

Example.—The construction of a blast furnace for a weekly production of 500 cwt. of pig iron is intended for the use of two-thirds of soft and one-third of hard charcoal, a cubic foot of the soft coal weighing 7 pounds, and one of hard coal, 10 pounds. The ores yielding 30 per cent. of iron will probably require an addition of 12 per cent. of limestone. One cubic foot of admixture weighs 86 lbs., and the relative consumption of fuel will amount to 120 lbs. when employing hot blast of 250° C.

According to these statements, the average weight of one cubic foot of the mixed fuel will be:—

$$y' = \frac{2}{3} 7 + \frac{1}{3} 10 = 8 \text{ lbs.}$$

and $\frac{k}{100y'}$ (the quantity of fuel required for the production of 1 lb. of iron) + $\frac{100 + c}{q' + y'}$ (the number of cubic feet of mixture corresponding to 1 lb. of iron) = $\frac{120}{800} + \frac{112}{86 \times 30} = 0.1974$; and supposing $Z = 16$ hours, it follows that

$$D = 0.8448 \sqrt[3]{0.1974 \frac{2}{3} \frac{50000}{7}} = 8.256 \text{ feet.}$$

According to what follows, the capacity of the furnace will therefore amount to

$$J=8.256^3 \times 1.6702=940 \text{ cubit feet.}$$

The other dimensions of blast furnaces usually stand in a certain proportion to the diameter of the belly. Lindauer states the average ratios to be

	Charcoal. <i>D.</i>	Coke. <i>D.</i>	Mineral coal. <i>D.</i>
Diameter of the furnace mouth	0.400	0.500	0.600
“ “ upper hearth	0.350	0.250	0.250
“ between the tuyeres	0.250	0.210	0.250
Height of the hearth (boshes included)	0.740	0.667	0.250
“ “ upper hearth	0.490	0.457	0.146
“ “ belly	0.292	0.113	0.506
“ “ boshes	0.464	0.842	0.644
“ “ shaft	3.004	2.378	1.200
Total height of furnace	4.500	4.000	2.600
Angle of the boshes	55°	65°	60°

From these members of the ratio the capacity of the different parts of the furnace may be calculated as follows:—

	Charcoal. <i>D₃</i>	Coke. <i>D₃</i>	Mineral coal. <i>D₃</i>
Capacity of the shaft	1.2270	1.0890	0.6158
“ “ belly	0.2293	0.0890	0.3972
“ “ boshes	0.1789	0.22: 8	0.0659
“ “ upper hearth	0.0350	0.0190	0.0072
	<u>J=1.6702</u>	<u>1.4268</u>	<u>1.0861</u>

Supposing the capacity of the whole furnace to = 1, the result will be—

	Charcoal. <i>J.</i>	Coke. <i>J.</i>	Mineral coal. <i>J.</i>
Capacity of the shaft	0.7347	0.7633	0.5670
“ “ belly	0.1373	0.0624	0.3658
“ “ boshes	0.1071	0.1611	0.0606
“ “ upper hearth	0.0209	0.0132	0.0066
	<u>J=1.0000</u>	<u>1.0000</u>	<u>1.0000</u>

In the above formulas it must be noticed that the weights of charcoal do not correspond with our own, as in the first place making due allowance for Austrian measures, there are no soft charcoals of a weight so light used in American furnaces, and our hard coals generally run from sixteen to twenty-two pounds to the bushel. Again, the mineral coal spoken of is bituminous raw coal which varies considerably in heating value, at least to so great a degree that the formula to be accurate should recognize not only the weight but the heating value of that

weight, or the weight of consumable carbon. What has been said of raw coal is equally true of coke, as that also varies considerably, and indeed fatally to the accuracy of any empirical formula. Again, from experiments made by Mr. Talcott, of Dover, N. J., reference to which has already been made, it is a fact ascertained from the construction of some furnaces that radiated heat from those furnaces is so great that a very appreciable difference in the consumption of fuel is found to exist, as has been proved by the re-erection of the same furnace with non-conducting chambers, having the internal outlines identically the same, and charges, &c., repeated as before alteration. This fact should be a recognized element in a formula which measures to minute decimals. There is, however, no other formula so accurate and comprehensively constructed, and which, with the fuel, limestones, and spathic ores of Germany, is more likely to give a basis of truth upon which the student may intelligently build his own formula, to meet the new emergency of a varied element in either the charge or in the furnace construction.

The following principle of procedure to obtain the same object and accuracy, has been suggested by Prof. Johnson, to whose report on the anthracite coals of the United States, we have referred heretofore. It appeared that he examined seven furnaces which required 501.3 tons anthracite per week, to 310.5 tons pig made in the same time, and they consumed 4.5 cwt. of coal to each ton of pig, for the purposes of heating their blast. The total amount of coal therefore would be 571.16 tons per week. This would give one ton pig to 1.84 ton coal (1 ton, 16 cwt., 3 qrs., 5.6 lbs. coal). If the coal had been pure C, and all had been changed into CO^2 , the weight of O would have been arrived at by the computa-

tion $\frac{16}{6} \times 1.84 = 4.905$, but if we take the average C at

88 per cent., we shall have $100 : .88 :: 4.906 : 4.316$. But the only source of O is the air, which has 28 parts by weight of Nitrogen to 8 of O. N+O then is equal to 36, hence $8 : 36 :: 4.316$ is to 19.422. As 13.22 cubic

ft. weigh 1 pound avoirdupois, 19.422 tons would represent 575,139 cubic feet of air. Hence, we can compute the amount of air delivered to furnace and hot-blast per minute, when we know the amount of iron made per day of twenty-four hours. Suppose the furnace, No. 1 at Catasauqua, makes 24 tons per day of 24 hours, then $24 \text{ hours} \times 60 \text{ min.} = 1440 \text{ minutes}$, and this divided by 24 tons = 60 minutes to ton, and the number of cubic feet of air required to do this work would be $\frac{575,139}{60} = 9587.6$ cubic feet per minute. Yet there is a

large waste of air between the cylinder valves and the charge to be provided for.

The seven furnaces received 22,569 cubic feet, per minute, into their blowing cylinders and the aggregate area of their boshes was 512.67 sq. ft. The average of C was reckoned at 85 per cent. of the anthracite. The quantity of anthracite to the ton of iron made was 1.84 as above. The time for making one ton pig was 34.4 minutes. The weight of C burned in that time was $.85 \times 1.84 = 1.564$ tons. This will require 2.66 times its weight of oxygen (in making CO^2), or 4.16 tons. As found above this will = 18.72 tons of air ($\frac{36}{8} \times 4.16$)

which at 29,612 cubic feet to the ton = 554,336 cubic feet air to one ton pig. But this was required for 34.4 minutes, which divided into $554,336 = 16,114 =$ the amount of air per minute to make a ton in 34.4 minutes. This principle is the same now as when Prof. Johnson suggested it, although the data must be altered, and could be easily adopted and would be sufficiently practical for most purposes of this kind.

From comparison of the furnaces above cited it appeared as Prof. Johnson says that "the production of one ton of pig iron per week is derived from $1\frac{3}{4}$ square feet of bosh—or one ton per day from every $12\frac{1}{4}$ square feet." General average seemed to prove that 1.08 horse-power, or better, $1\frac{1}{4}$ horse-power is equal to the produce of 1

ton per week. This is computed at an average pressure of 2.04 pounds per square inch.

It would be, thus, very easy, by collecting the data from furnaces using certain ores, fuel, and limestone, or other flux, to arrive at a practical conclusion which would be safe and satisfactory, but only applicable to the ores, fluxes, and coal of the region for which the computations were made.

In respect to the size of furnaces and the wearing or burning out of furnaces and other matters of interest in the comparative economy of European and American furnaces the *American Journal of Mining* (May 22, 1869) makes the following remarks:—

We learn by a private letter received from a distinguished metallurgist in Europe, some facts concerning the iron industry of foreign countries, which are calculated to gratify American iron-masters. This gentleman writes that he has spent the past winter in travelling among the French and English furnaces, and gives it as the opinion resulting from his observations, that many of the recently constructed and systematically managed establishments of the United States have nothing to fear from a comparison with the very best in Europe. In fact, there are some respects in which the iron-masters of this country are decidedly in advance of their transatlantic compeers. The ever-increasing consciousness of the necessity, or at least economy of a very high temperature in the blast, is far more generally acknowledged and obeyed in this country than in Europe; and the average number of workmen required to perform the usual labor about the furnaces is much greater there than here.

Our correspondent gives the palm, among the works which he visited, to the furnaces near Middleboro, in the Cleveland district. "Everything here," he says, "is new, practical, and neat even to elegance." Whether, however, in the colossal furnaces of that neighborhood, the limits of economy have not been passed, is a serious question. The two furnaces at Rosedale are 103 feet high and 27 feet in the boshes. Certainly their production of 80 or 90 tons per 24 hours, great as it is, seems to be below the proportion of their vast dimensions. Probably the use of the Lurmann cinder-block, which has been adopted at some of the works, will be found especially advantageous in raising the product of very large furnaces, since it brings the slag discharge much nearer the centre of heat, to say nothing of other favorable effects.

One point of difference between American and foreign blast furnaces is not in our favor. We are not able to keep as long in blast as do the Europeans. This complaint is quite general among us; and it is well worth while to inquire, whether the difficulty arises from a defect in the quality of our natural or manufactured fire-proof material. With a view to answer this question, careful experiments have been made abroad, upon samples of American clay, and bricks furnished by W. M. Lyon, Esq., of Pittsburg, and the results have just been communicated to us by Mr. Geo. Asmus, under whose direction they were instituted.

It was found that our "Mount Savage" fire-brick excels the *best* varieties in Scotland, Germany or Belgium, and that our "Star" at least equals them. A third brand, of cheap American brick, the "Porter," showed itself not sufficiently fire-proof to be used even in the upper parts of blast furnaces. These experiments do not by any means prove that there are not many other kinds of American fire-brick as good as those mentioned. In fact, we have ourselves obtained and manufactured material from New Jersey, which successfully resisted tests before which the famous "Stourbridge" brick gave way. The question to be answered in these experiments was merely, whether it would pay to import Scotch or German brick, or the assumption that all American material is defective. This question is now clearly answered in the negative; and if "Mount Savage," or "Star" bricks do not hold out as long as "Garnkirk," the reasons must be sought elsewhere than in the raw material.

Most complaints of this kind come from furnaces which smelt the very rich ores of Lake Superior, and that, too, with extremely small additions of lime. Under these circumstances, the formation of cinder at the expense of the alumina of the fire-brick is inevitable. The evil is aggravated when the blast is not strong, as, for instance, at the charcoal furnaces of Lake Superior, when the pressure is but $1\frac{1}{2}$ pounds. The zone of fusion here becomes annular, and hugs the walls, producing such a rapid action upon them, that it is not surprising that the blasts in that neighborhood seldom last longer than twelve or fifteen months.

Careful experiments only can determine whether it would be wise to change the present proportion of flux, and the pressure of blast, to gain the advantage of longer campaigns. Such questions cannot be flippantly answered *a priori*. One thing, however, is now certain. We do not need to look for better material in the construction of furnaces than our own country affords.

The following remarks, which we find in Kerl's Me-

tallurgy by Crookes and Röhrig, are suggestive to American furnace-masters, although intended for coke furnaces, and, in the former remarks, for spathic ores.

The Styrian Blauöfen* with one blast pipe $1\frac{1}{4}$ inches in diameter require from 250 to 300 cubic feet of blast per minute; the largest furnaces, having five blast pipes 3 inches in diameter and a pressure of $2\frac{1}{2}$ or 3 lbs., require about 7500 cubic feet. The large Scotch furnaces require per ton of pig iron from 5000 to 5500, per minute 90, and per cubic metre of the furnace shaft 0.50 cubic metre of blast. Some furnaces at Dowlais, having a capacity of 230 cubic metres, consume 180 cubic metres of blast. The furnaces in Staffordshire and Cleveland, smelting poorer ores than the Scotch furnaces require from 6000 to 7000 cubic metres of hot blast per ton of gray iron, or from 0.55 to 0.60 cubic metre per 1 cubic metre of capacity, and 8000 and 0.70 cubic metres respectively, when using cold blast. In England, 25 tons of blast are estimated to be required per ton of pig iron from clay-ironstone, and 8 tons of blast per ton of pig iron from blackband. In the latter case 34 cwts. of pig iron and slag result per cubic yard of the furnace, and in the former 2.5 cwts. per week; hence, 8 tons of blast are required for the production of 1 ton of iron and slag from clay-ironstone, and 4 tons of blast for a similar production from blackband.

* In our previous notice of the Blauofen (pp. 293, 294) we have quoted Mr. Overman, who considered that the English translation of the name was preferable to the use of the German form. He has made it "Blue oven." There are reasonable doubts that this is the signification of the original word, and Prof. Maynard, of the Polytechnic Institute, at Troy, N. Y., writes us, that, although the usual signification is as above indicated the present form, blauofen is an Austrian corruption of the German *Blase ofen*, as he was assured when in Germany, and the corruption arose from the Austrian predilection for broad pronunciation whereby the German *Blase* became *Blā* and finally *blauofen*. Mr. Overman was very decided in his opinions, as we learn from his proof-reader, and we think traced the name to the fact of the blue flame more fully developed in this furnace, which was the first step from the low to the present form of high blast furnaces. But we are persuaded as a flame of this color seldom, if ever, arises from these charcoal furnaces, that Prof. Maynard's remarks are correct, and the name should not be translated.

Belgian coke furnaces receive from 2880 to 3640 cubic feet of blast per minute.

The proportionally small production of some large furnaces in comparison with small furnaces is frequently caused by an insufficiency of blast, as in the quantity of oxygen required for the charged fuel is then wanting, and injures the temperature, the consumption of fuel, and the quality of the resulting pig iron. At Ulverstone, the weekly production of 593 tons of pig iron has been increased to 684 tons by increasing the blast from 9000 to 10,000 cubic feet per minute. The introduction of *too much* blast into a furnace increases the consumption of fuel without increasing the production, but sometimes lessening it. The slags are cooled by the blast; the gases ascend with too great a velocity, injuring the reduction and carbonization, and owing to the quicker process, the pig iron produced will be less carbonized and more difficult to fuse. The same effect, caused by too large or too small a blast, is produced by an increase or decrease of the fuel whilst keeping the proper quantity of blast; the production will be lessened, and the consumption of fuel increased.

We are indebted to the same authority for the following summary of points important in the examination of blast furnaces.

When *inspecting blast furnaces*, the following points have to be taken into consideration. The situation, extent, and motive power of the establishment, and the nature of the ores (kind of ore, injurious or advantageous associates, analyses, behavior in smelting, percentage of iron, cost); the assaying of the ores (the manner of selecting the samples, fluxes, furnaces, length of smelting, consumption of fuel); the weathering of the ores (time, effect, artificial watering); the roasting of the ores (roasted or not roasted in kilns or otherwise, kind of fuel and consumption of fuel, quantity roasted in a certain time, number of workmen, wages, cost of roasting); the breaking up of the ores (the method employed and its effect, size of the broken ores, quantity, number of workmen, wages, cost of breaking); the fluxes

(quality, composition, application in raw or burned state, mode of dividing the fluxes, size of the broken pieces, weight per cubic foot, percentage of the quantity added, charging separately or in admixture with the ore, cost); the fuel (kinds of fuel, quality, amount of ash and moisture, injurious components of the ash, size of the pieces, weight of one cubic foot, volume of the delivered fuel, &c., vessels for measuring, if used, method of carbonizing or coking, price); the ore mixture, including the fluxes (rules adopted, varieties of iron ores, fluxes and the manner in which they are mixed with the ore, average percentage of iron, lifts, size of the charging vessels, the size of the ore heaps when mixed with the fluxes (the ores for charcoal furnaces are mixed with the fluxes, by placing ores and fluxes in alternate layers one above the other, the ore thus mixed forms heaps of the shape of a truncated pyramid and is termed in German "Moller"), the weight of one cubic foot dry and wet, working tools, number of workmen, working cost); the iron blast furnaces (construction of the furnace, materials used for the different parts of the furnace, dimensions of the furnace, capacity of the hearth, construction of the apparatus for the collecting the waste gases, age of furnace since the blowing in); the tuyeres (number and dimensions of the tuyeres, material of which they are made, open or closed, dry or cooled with water, the position of the tuyeres with regard to their deviation from the horizontal line, height of the tuyeres above the bottom stone, bright or dark tuyeres, with or without nose); the blast (blast engine and its motive power, regulators, blast-heating stoves and the mode of firing, blast mains, construction, position and diameter of the blow pipe, temperature, pressure and volume of blast per minute, the volume calculated from the blast engine and from the blowpipe, loss of blast, apparatus for measuring the temperature and pressure of the blast); the charging (size of one charge of fuel and ore, with regard to volume and to weight, charging vessels and other apparatus required, mode of charging, number of charges descending the furnace in twenty-four hours, with con-

sideration of the tappings when the blast is shut off, the depth to which the charges descend in a given time, time in which the charges enter before the tuyeres, and how many charges the furnace contains above the tuyeres, the descent of charges required for the regular process, mode of keeping account of the charges); the manipulations in and before the hearth (removal of the slag and the pig iron, cleaning the hearth and the tuyeres, formation of the slag drift and the gutters or feeders, and moulds for receiving the liquid iron, length of the operation, mode of blowing out, number of workmen, wages, tools, drawings of blown-out furnaces); the products, such as pig iron (varieties, quality, application, the production in twenty-four hours or per week, the yield in comparison to the assay, consumption of fuel, ore and fluxes per cwt. of pig iron, cost per cwt.); the slags (nature of the normal and abnormal slags, transport of the slags from the smelting works, further application of the slags for recovering wash iron, building purposes, &c.); lead (tapping off and further application); waste gases (quantity, temperature, color, rapidity of the ascent, fuming, charge at the different processes, methods of collecting and applying); the deposits and other products (cyanide of potassium, furnace cadmia or calamine) (Ofenbruch, Gichtschwamm).

Effects of Moist Atmosphere.—The following, from European and especially Austrian latitude, is, as we shall see, applicable in a degree to American practice.*

The quantity of moisture introduced into the blast furnace along with the blast depends on the quantity of blast and on the hygroscopic state of the atmosphere, and influences the quality of the iron and the consumption of fuel owing to its cooling effect. With regard to this circumstance the yield of blast furnaces is more favorable in spring and winter than in summer and autumn. In this country, where the atmospheric air in common dry weather contains 142 per cent. of moisture, and the weekly production of 128 tons of pig iron requires 3000 tons of air (25 : 1), along with this quantity of blast nearly 43 tons of water are introduced in the furnace; this amount

* Kerl's Met. Crookes and Röhrig, pp. 486, 496.

may be doubled in summer and autumn. At the Dowlais Iron Works the pig iron produced in winter was shown by a comparison of several years to be better by from four to five per cent. than that produced in summer; the other circumstances were the same in both seasons.

According to Weisse's and Ech's investigations, the months may be classified into the dry and moist months as follows:—

January, December, February . . .	5 : 5 : 6
November, March, April . . .	6 : 7 : 8
October, May, June . . .	8 : 10 : 11
September, August, July . . .	11 : 12 : 13

The summer stands therefore, in proportion to the winter as 37 : 65, or 4 : 7; and experiments have proved that the effect of the blast in summer and in winter is in the proportion of 5 : 6.

According to Rogers, air of 0° contains $\frac{1}{8000}$ of its own weight of water, air of 15° C. one-eightieth, of 30° C. one-fortieth; therefore in very hot weather the production of iron may be less by 20 per cent. In England 1 cubic metre of air is supposed to contain on an average 8.7 grammes of water. Balling estimates the quantity of water which is introduced in 24 hours into a blast furnace of medium size by means of the blast to be about 800 lbs.

The above, in the main, has been proven true in our land, wherever any care has been exercised to ascertain the facts. During the spring of 1868 there was, in parts of Pennsylvania, including, indeed, nearly the entire State, a long-continued rainy season. It was particularly noticed that the iron made during that season was not so largely gray, or foundry, as it had been, and while, in some instances, foundry iron was made as usual, in a very large majority of cases there was nothing to which to attribute the change but the weather. and the corroboration was found not only in the fact that similar weather had been before followed by just such a state in the furnace products, but, in the fact that when dry weather returned, the furnaces, in a few days after the change, returned to their previous quality and quantity of working. Some have attributed the difference in some places to the condition of the ore when delivered in summer and in winter, but such a cause is

not sufficient to meet the case as it presents itself in some instances wherein it is plainly shown that the ores are in as good condition in winter as in summer, and yet the same results have followed. The remedy can be found in lessening the burden of ore or in increasing the blast in heat and quantity, or the amount of coal, as the case may require.

Unaccountable Difficulties.—We have thought it well to close this part of the general subject with a letter which we received not long ago from a prominent iron-master whose experience is large, and who, perhaps, is as competent to explain and to overcome difficulties as is any one in our country. It will better illustrate the assertion, that, after all our knowledge and practice, there will always remain sufficient room for further information and improvement, and that no one should feel himself so securely beyond all reverse or surprise that he may not at some time wish that he knew more of what has become to him the mysteries of metallurgy.

The furnace No. 2, Scranton, Pa., had been an excellent furnace; yielding regularly, largely, and satisfactory in all respects, but suddenly a difficulty occurred, and in answer to our inquiries we received the following from the Superintendent.

“As you are aware, the size of tunnel-head was enlarged from a diameter of eight feet to that of eleven feet; in addition to this increase to the diameter of the top, the mode of filling was also changed, the former method being to fill with a charge of 1800 pounds of coal, other materials proportioned to that, from three barrows, through three doors, equidistant from each other. The new plan was simply to double the charge and fill through six doors, my impression being that I would thereby secure a more uniform distribution of the stock. The “blowing-in” was accomplished without a single unfavorable indication, and the furnace worked finely for about one month, and then, while making mottled iron on a very fine cinder, suddenly, with scarcely an hour’s premonition, closed up, so that by no subsequent efforts could the blast be

made to penetrate the stock. Of course, it had to be shovelled out; this was done as quickly as possible, and a second effort inaugurated, it being supposed that the failure was caused by filling the ore too far from the centre of the crucible. That difficulty was sought to be obviated by the introduction of schute plates at top, projecting two feet towards the centre, thus practically reducing the diameter to seven feet; filling was continued through six doors. The second time the "blowing-in" was satisfactorily done, and the smelting operation went on smoothly for six weeks, when precisely the same difficulty occurred, under exactly similar circumstances, though the results were not quite so bad. By placing tuyeres high up in the breasts, the blast was forced through, and after two weeks' incessant fighting, the scaffold was so far worked out that the iron would separate from the slag. Since then there has been a gradual improvement with no recurrence of the trouble. Immediately after the last trouble I again changed the mode of filling to a charge of 1800 pounds through three doors, from the impression that the other method was forming a continuous ring of ore, which, under certain conditions, would become plastic, and while slipping down the boshes, would close up so as to form a pastry arch or barrier to the passage of the blast, and that by filling through one set of three doors by day, and through another set at night, the ore would become so thoroughly scattered and intermixed with the coal as to prevent a recurrence of that special difficulty. The results thus far have been such as to strengthen the impression that the old way of working is the best, or at least that the eight-foot tunnel-head is nearer the true size than is the larger diameter. What most perplexed me in the working of this furnace was the occurrence of the trouble with a cinder that had always before been a sure indication of an entirely healthy state, and which never caused the least apprehension of difficulty.

When I determined to enlarge the tunnel-head, I had conceived the idea that scaffolding was caused by the larger lumps of coal rolling out to the walls of the cru-

cible as the stock descended, and by keeping that part of the furnace most free for the passage of blast, tended to concentrate the heat along the walls to a degree that clinkered the coal and caused its adhesion to the bricks until large quantities having accumulated, they would become loosened, and falling into the hearth, produce that miserable substance technically known as "scaffold cinder," always the dread of a furnace-man, but my late trials have taken that conceit out of me, and have substituted the belief that it is the ore and not the coal that is properly chargeable with the cause of disaster, and that a thorough mixing of materials, with their uniform distribution was a more important consideration than the exact form of the furnace.

We are now making nothing but forge iron, mottled and white; never make foundry pig, except by special effort, and find it difficult under the most favorable circumstances to produce a satisfactory article. Our largest furnace (20 feet boshes), is now averaging 250 tons forge pig weekly. Our highest weekly product was made by a nineteen feet furnace, and reached $375\frac{1}{2}$ tons; we were then using considerable fossil, that was easily smelted; at this time we use nothing but magnetic ores."

We would say, in conclusion, that the above indicates, what many masters have experienced, that although there are times when no explanation seems sufficient to meet the demands of the case and to solve the problem, there is no emergency, but has its cause and cure, and only the lack of more knowledge and perhaps of more thoughtful experience, intervenes between a full resolution of the mystery and a proper remedy for the difficulty.

PART III.

CHAPTER I.

MANUFACTURE OF MALLEABLE IRON.

IN treating upon this subject we have thought it best to introduce the remarks of Mr. Overman, with certain alterations. Although these remarks may, in some small degree, be modified by the fact that they were written nearly twenty years ago, they are substantially, with the corrections we have made, suitable to the present day, and introduce the subject satisfactorily. We shall add the improved processes, furnaces, and machinery afterward.

[The manufacture of malleable iron involves two fundamental operations: namely, the removal of impurities from the ore and from the crude metal. The first, which consists in the removal of impurities, and the virtification of the earthy admixtures in the ore, is effected by a variety of methods. If the amount of impurities in the ore is large, an intermediate method is employed to remove them; that is, metal of greater or less purity is manufactured in the blast furnace. But if the amount of impurities is excessive, or if the metal from the blast furnace is very impure, as is often the case even in gray charcoal pig, and quite generally the case in anthracite and coke iron, the refining fire is resorted to, before the metal is subjected to the process by which it is converted into bar or fibrous iron. The second operation, though effected by a variety of methods and by a diversity of apparatus, consists mainly in a semi-fusion of the metal. In this condition, it is stirred and worked by manual labor, with the object of exposing the

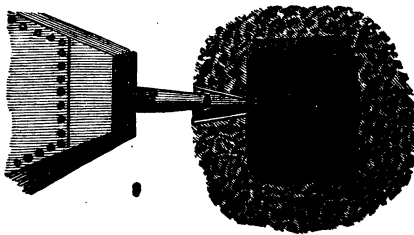
smallest particles of the metal to the influence of the atmospheric oxygen.

In this chapter, we shall endeavor to describe the principal forms of apparatus at present in use in various parts of the world, and especially in the United States; we shall attempt to indicate the methods by which the operations in the manufacture of wrought iron are performed; and we shall close the chapter by some theoretical investigations to which we would invite the attention of the manufacturer no less than the philosopher.

I. *Persian Mode of making Iron.*

The most ancient method of manufacturing iron is at present practised in Persia; and, as far as we can ascertain from the published reports of travellers, whose descriptions, while they slightly vary in detail, agree in relation to the uniformity of the principle, this method is practised throughout Asia. The manipulation is as follows: A hearth, or a mould with fine charcoal, or clean charcoal dust—that is, a semicircular hole from six to twelve inches in depth, and from twelve to twenty-four inches in width, as represented in Fig. 149—is formed. The dark shading in the figure illustrates the

Fig. 149.

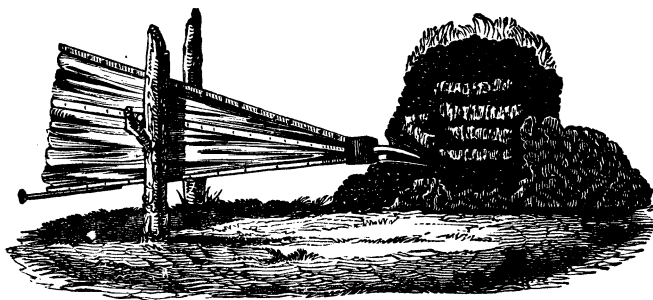


Ground-plan of a Persian forge fire.

lining of charcoal dust; the form of this lining is sometimes round, and sometimes square. Before the dust is put into the hearth, it is moistened, well mixed, and pounded as closely as possible. The lining will, of

course, be perfect, in proportion to the fineness of the dust. The bottom especially should be hard, to resist the action of the blast. Into this basin, the blast is conducted by means of a clay tuyere, or a piece of crockery, situated a short distance above the bottom of the basin. The bellows are urged by manual power. Fig. 150 ex-

Fig. 150.



Aslatic or Persian method of making iron.

hibits a section of the basin, and the situation of the bellows. In the bottom of the basin, medium-sized charcoal is laid to the height of several inches, covered by a layer of ore in pieces of the size of hazelnuts. Where no compact ore can be obtained, the fine ore may be cemented by being moistened, and then dried and broken. But the native compact ore is preferable, because, it contains fewer impurities. Upon this layer of ore a layer of charcoal is placed, and then alternately ore and charcoal until five or six strata are piled. The whole is covered by charcoal of moderate size, firmly pounded. Fire is then introduced at the tuyere, and the bellows gently moved, so as to expel all the water contained in the mass, before a full heat for the reduction of the ore is given. When the water is supposed to be driven off, the bellows are urged more strongly, and the heat increased. The ore is then reduced, and iron liberated in a metallic state. The whole process lasts from three to four hours, at the end of which time twenty-five or thirty pounds of iron may be removed by tongs,

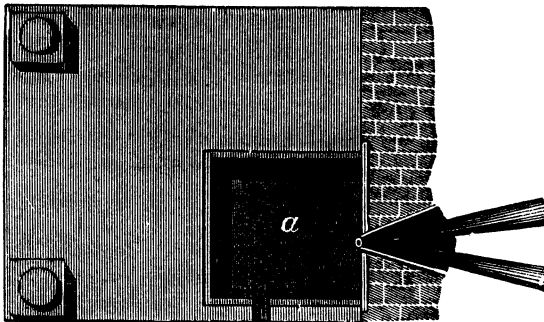
and forged by means of sledge-hammers. Of course, the desirable shape is not produced until the metal is heated and reheated several times. After the iron from one heat is forged, the clinkers are removed, and another coating of charcoal thrown on; in fact, a renewal of the whole process is required.

In this process, none but the best kind of red iron ore, or specular iron is used; and it is questionable whether any but the richest of this ore can be employed. The iron manufactured is very strong and tenacious; from which the sabres of Damascus, and the neat and delicate, though very powerful Damascene gun-barrels, as well as weapons of nearly every kind, are wrought.

II. *Catalan Forge.*

This forge is employed in Vermont and New York, to smelt the magnetic ores of these States. It is there called the blomary fire. The form of this fire is nearly uniform everywhere. Fig. 151 represents a Catalan fire,

Fig. 151.

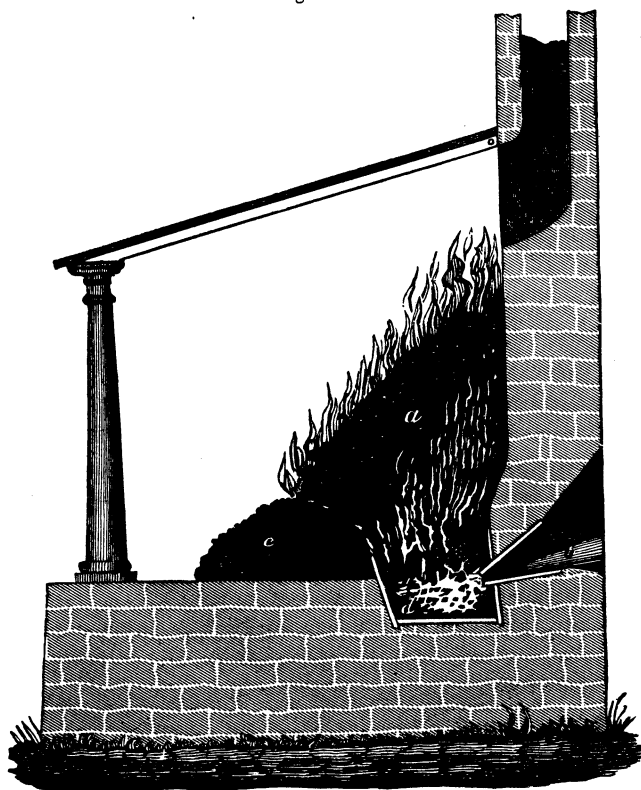


Ground-plan of a forge fire.

seen from above. The whole is a level hearth of stonework from six to eight feet square, at the corner of which is the fireplace, from twenty-four to thirty inches square, and from fifteen to eighteen, often twenty, inches in depth. Inside it is lined with cast iron plates, the bottom

plate being from two to three inches thick. Fig. 152 represents a cross section through the fireplace and

Fig. 152.



Blomary fire.

tuyere, commonly called the iron. *a* represents the fireplace, which, as remarked above, is of various dimensions. The tuyere *b* is from seven to eight inches above the bottom, and more or less inclined, according to circumstances. The blast is produced by wooden bellows of the common form, or, more generally, by square, wooden cylinders, urged by waterwheels. The ore chiefly employed is the crystalline magnetic ore. This ore very readily falls to a coarse sand, and when roasted, varies from the size of a pea to the finest grain. Some-

times the ore is employed without roasting. In the working of such fires, much depends on the skill and experience of the workmen. The result is subject to considerable variation; that is to say, the result depends on the circumstance whether economy of coal or that of ore is our leading object. Thus, a modification is required in the construction either of the whole apparatus, or in parts of it. The manipulation varies in many respects. One workman, by inclining his tuyere to the bottom, saves coal at the expense of obtaining a poor yield. Another, by carrying his tuyere iron more horizontally at the commencement, obtains a larger amount of iron, though at the sacrifice of coal. Good workmen pay great attention to the tuyere, and alter its dip according to the state of the operation. The general manipulation is as follows: The hearth is lined with a good coating of charcoal dust; and the fire-plate, or the plate opposite the blast, is lined with coarse ore, in case any is at our disposal. If no coarse ore is employed, the hearth is filled with coal, and the small ore piled against a dam of coal dust opposite the tuyere. The blast is at first urged gently, and directly upon the ore; while the coal above the tuyere is kept cool. Four hundred pounds of ore is the common charge, two-thirds of which are thus smelted; and the remaining third, generally the finest ore, is held in reserve to be thrown on the charcoal when the fire becomes too brisk. The charcoal is piled to the height of two, sometimes even three and four feet, according to the amount of ore to be smelted. When the blast has been applied for an hour and a half, or two hours, most of the iron is melted, and forms a pasty mass at the bottom of the hearth. The blast may now be urged more strongly, and if any pasty or spongy mass yet remains, it may be brought within the range of the blast, and melted down. In a short time, the iron is revived; and the scoriæ are permitted to flow through the tapping-hole *c*, so that but a small quantity of cinder remains at the bottom. By means of iron bars, the lump of pasty iron is brought before the tuyere. If the iron is too pasty to be lifted, the tuyere is made to

dip into the hearth. In this way, the iron is raised from the bottom directly before, or to a point above the tuyere, until it is welded into a coherent ball twelve or fifteen inches in diameter. This ball is brought to the hammer or squeezer, and shingled into a bloom, which is either cut in pieces to be stretched by a hammer, or sent to the rolling mill to be formed into marketable bar iron.

a. A mixture of fibrous iron, cast iron, and steel—an aggregation of unavoidable irregularities—is the result of the above process. The quality of the iron depends entirely upon the quality of the ore. No opportunities are presented by which any skill or ingenuity can create improvements in this process. Poor ores cannot be smelted at all; but rich ores, like those at Lake Champlain, or in Missouri, Michigan, &c., or even the hydrates of Alabama, may be smelted to advantage; the latter with a prospect of economy. In some countries, where much larger fires than the one we have mentioned are employed, balls of 200 or 300 pounds weight are produced; but such large masses cannot be worked with facility, and are always of inferior quality. It is not advisable to make, at one smelting, balls heavier than 100 pounds.

In Vermont, where the rich magnetic ores were employed for this kind of work, a ton of blooms formerly cost about forty dollars. To produce this quantity, four tons of ore and three hundred bushels of charcoal are required. Wages of workmen per ton, ten dollars.

b. An improvement upon the Catalan forge is the stück oven described already. But little explanation is required to exhibit the connection between the two manipulations. So heavy are the masses of iron in the stück oven, that powerful machinery, as well as a large number of workmen, is required in working them. The salamander, when lifted out of the furnace, is cut into pieces of 100 or 150 pounds weight. These pieces are reheated in a common forge, or Catalan fire; a portion of the cast iron melts out of it; and what remains is generally the best iron, and is called the bloom. From

this term it is probable that our English word "bloom" is derived. Sometimes the bloom is in part steel, according to the state of the furnace, and the kind of ore used; but, generally, it is fibrous iron. The cast iron which results from the reheating is worked, by the common method, into fibrous iron. So expensive is the operation in the stück oven, and so imperfect the iron which it produces, that this furnace is now generally abandoned. Both the Catalan forge and the stück oven are impracticable where ores containing less metal than forty per cent. are to be smelted. Any foreign matter in the ore is injurious.

Many ingenious contrivances have been devised to convert ore, by one manipulation, directly into bar iron or steel. These contrivances are local, and vary according to the quality of the ore, and the intelligence of the operator.

III. *German Forge.*

The most successful method of manufacturing charcoal wrought iron is by means of the German refining forge,

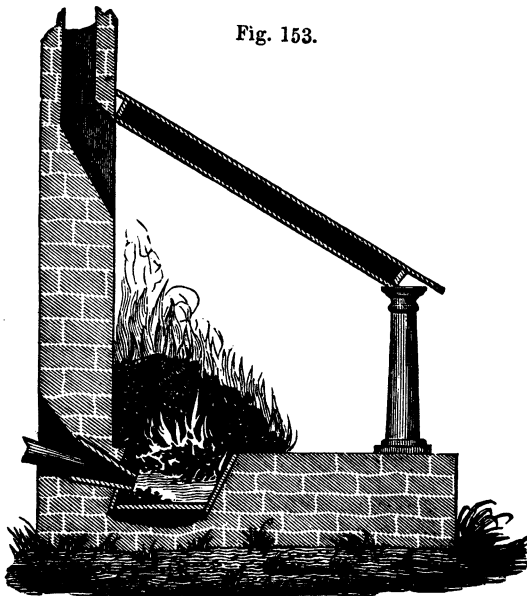
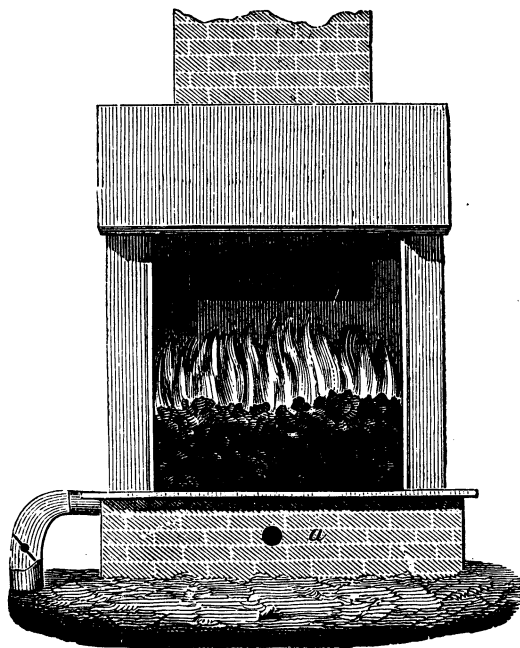


Fig. 153.

Forge fire.

or the bloomery fires of Pennsylvania. These forges not only produce good iron at reasonable prices, but they afford all the facilities presented by differently constructed apparatus. Fig. 153 represents a section of the German forge, in which the location of the hearth is shown. The hearth is lined with cast-iron plates; the bottom is generally kept cool by a current of water circulating in pipes below it. Three or four inches above the bottom, there is a row of holes, through which the cinder is let off. Through the tuyere, which is hollow, a current of water circulates. Frequently, the back

Fig. 154.

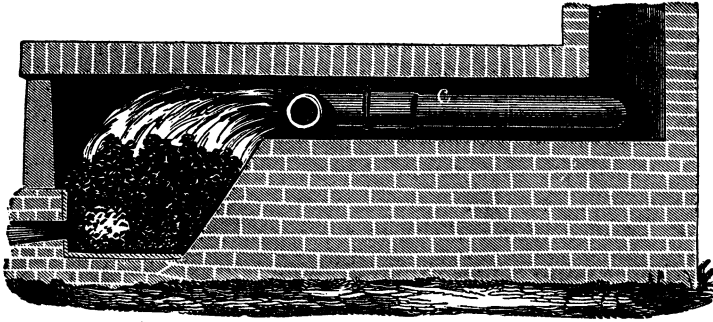


Forge fire.

part of the hearth is raised, for the purpose of putting in hot air pipes, as shown at *c*, Fig. 155. Fig. 153 exhibits a better arrangement for heating the blast. *d* represents a hollow roof plate, of sheet iron, through which the blast passes. The blast for this kind of fire is produced either by wooden or by iron cylinder bellows.

a. The iron employed in this forge is of the various kinds of pig metal, from the white pig which contains

Fig. 155.



Heating the blast on a forge fire.

a small amount of] graphitic [carbon, to the gray and white metal which contains carbon in considerable quantity. The construction of the apparatus depends scarcely at all upon the kind of metal worked. By varying the treatment of the material, in the course of the manipulation, the same results may, in the great majority of cases, be produced. Gray metal requires a higher heat at first than white metal; besides, more time is required, and a greater amount of fuel consumed, in working it. In this; as in every case, white metal containing a large amount of carbon is, when smelted by hot blast, the worst of all metals for the manufacture of a satisfactory iron. Should gray metal, smelted from the same stock as white metal, by small burden, work slowly, and consume more fuel than the latter, there is a greater prospect of producing a better article. An exception from this rule occurs only where ore of the first quality is smelted by charcoal and coal blast. White metal, smelted by small burden and poor ore, or anthracite or coke, is always inferior; it works so fast that no time is afforded for the removal of the impurities combined with it. Where gray metal is worked, a greater chance of purifying the melted iron "before it comes to nature"*

* Term used to signify the transition state from cast iron to malleable.

is presented. These remarks do not apply to white iron made by charging the blast furnace with a heavy burden of ore. At the close of the chapter, we shall speak at greater length on this subject. In this place, we simply wish to draw the attention of the manufacturer to this important matter; because his success depends, in a very high degree, upon a clear understanding of the qualities of the metal, and of the metal, and of the modes of working it.

b. The form of the basin of the hearth, the height of the tuyere, and the pressure and the quantity of the blast, cannot be fixed by any general rule, and depend on coal, metal, and the workmen. We shall endeavor to explain the leading principles in each case; but their application is to be varied according to local circumstances.

c. The quality of the charcoal determines, to a certain extent, the dimensions of the hearth, the dip of the tuyere, and the pressure of the blast, as well as the amount of metal to be smelted by one heat. Soft coal, from pine wood and poplar, requires a larger and deeper fire, a greater dip of the tuyere, and weaker blast, than charcoal from hickory and maple. Soft coal works more slowly than hard coal. Dirty or sandy coal, which has been received from the coalings in wet weather, or which has been exposed to sand or mud in the yard, should be refused altogether, or at least carefully dried and cleaned; because each pound of sand removes three or four pounds of iron, for no conceivable purpose whatever. Coal that is not larger than an egg will answer tolerably well for a blomary fire; but strong and heavy coal is far more serviceable. In the preparation of coal for the blomary and the blast furnace, we are guided by different rules; that is to say, the small coal from the coalings is taken to the former, and the large coal to the latter. It should always be remembered that coal which contains sand and dirt is far more injurious in the forge than in the blast furnace.

d. So great are the practical difficulties in this kind of work, that fluxes are employed to a very limited extent. Hammer-slag* is sometimes used as a flux. This is a very useful material; it facilitates the work, and improves the iron. Water is another means of fluxing. In the first place, it cools the iron, and thus gives the blast a chance of playing upon it to advantage. In the second place, it is decomposed by red-hot iron; its oxygen is retained, and forms peroxide of iron, which readily combines with silex. For the purpose of retarding the working of the iron, workmen are in the habit of throwing sand, dry clay, or even loam upon the fire. This is inexcusable ignorance, or at least gross sluggishness. If proper care and industry are exercised, the iron will not come too fast, and if it does, the application of sand will only augment the evil. At any rate, it is highly injurious to the quantity and quality of the iron produced.

e. The fireplace is always of a square form, varying in size according to circumstances, and lined throughout with cast-iron plates. To secure the stability of the apparatus, these plates should be well screwed together. The plate nearest to the workman, called the cinder or work-plate, should especially be solid, because a great deal of the manipulation is done on this plate. The plates around the fire are generally laid in a somewhat sloping position, more for the purpose, we presume, of facilitating the lifting out of the bloom, and of making the dust stick, than for anything else. The tuyere plate is generally inclined into the hearth, partly with the object of facilitating the dipping of the tuyere, and partly with the object of cooling that plate. The blast is regulated by a valve (Fig. 154), which should be as close as possible to the tuyere, to facilitate the labors of the workmen. The tuyere, as before remarked, is a water tuyere, which, after its inclination has been determined, is firmly fastened in its place. The nozzle of the blast pipe is to be movable; it can thus be dipped

* The scales struck off from bars under the hammer.

into the hearth, or moved horizontally, so as to drive the blast towards any portion of the hearth. The width of the tuyere and the nozzle depends on the quantity of metal melted at once; but it seldom exceeds two superficial inches. The form of the tuyeres is generally that of a half circle \ominus ; but sometimes that of a circle. The depth of the fireplace varies according to the quality of the metal to be refined. Nine inches will be sufficient for mottled or gray iron; but white iron, of small burden, require a depth of ten or twelve inches. The better the metal the less the depth of hearth required. A deep hearth consumes more fuel, and works more slowly, than a shallow hearth; but if worked with proper attention, the product is superior. Inferior workmen require deep fires, as well as hot-short and cold-short metal. Shallow fires work fast, but require excellent metal or very expert workmen; because, if anything goes wrong in them, heavy losses are experienced.

A number of workmen draw the tuyere, to a greater or less extent, into the hearth. This is productive of no real benefit. Though by this means we are enabled to carry the blast a little further into the fire, the advantage we derive from it scarcely amounts to anything. If it is our desire that the metal should flow down, directly through the current of the blast, our object may be effected if the tuyere reaches but a short distance into the coal. Besides, by drawing the tuyere, its plate is sooner destroyed than where the tuyere is close. We must regulate the dip of the tuyere according to the metal we are smelting. Gray, and hot or cold-short metal, and soft coal, require a greater dip than good metal and hard coal. Nevertheless, the whole dip does not vary more than from 7° to 15° .

f. The manipulation at a blomary fire varies according to the quality of the metal with which we have to deal. Therefore, our descriptions must be restricted to one particular metal, or at least to a metal smelted from the same kind of ore. We shall confine our attention to gray or half gray metal, and introduce such remarks oc-

asionally as will indicate the method by which other kinds of metal are worked.

When the hearth is in proper order, and when the blast and everything else are prepared, the interior of the fireplace is lined with charcoal dust, which ought to be free from sand and other impurities. The finer the dust, the more serviceable it will be. Good fire-clay water thrown over it will, when the whole mass is well pounded, make it more adhesive. Pieces of refractory ore, of good quality, and even good qualities of cinder, are sometimes used in lining. These materials are decidedly preferable to charcoal; but they require more attention on the part of the workmen. Coal is then thrown on, and the fire kindled. As the fire rises, iron may be melted down. The amount of coal, or the size of the heap above the tuyere, varies according to the metal. A height of from twelve to eighteen inches is sufficient for gray metal; but for white metal the height of the coal should be twenty-four inches. When the fire has thoroughly penetrated the coal, the degree of which should be higher for white than for gray metal, the broken metal is thrown in parcels weighing from seventy to eighty pounds upon the top of the coal above the tuyere. But white metal is thrown more from the tuyere, in case a charge of more than 120 pounds is melted at once, which is frequently accomplished where the metal is good, and competent workmen are engaged. Where the charges are small, all the metal is thrown on at once. The blast is applied moderately; the tuyere is made to dip very slightly; coal is constantly supplied; and in case iron is left to be smelted, it is thrown on the heap. In due time, the iron melts into the bottom of the fireplace, and is more or less liquid. If the metal is gray, and if it contains a large amount of foreign matter, the process proves to be slow, for there are no indications of solidification. In this case the workman proceeds to increase the dip of the tuyere, to blow upon the iron, and to stir it repeatedly by means of iron bars. If, in consequence of this manipulation, the cinder increases on the top of the iron, it may be let off, and thrown

away, for such cinder is useless. When this is removed, the iron will be exposed in a greater degree to the action of the blast. If the metal still shows no signs of becoming pasty, hammer-slag or rich iron ore may be thrown upon the fire, and melted down upon the iron. The metal, when mottled iron, must be bad and gray indeed if hammer-slag or rich ore fails to "bring it to nature;" or if, when it is gray iron, either of these fails to bring it to a state of boiling.* Iron and cinder will then rise spontaneously, and move before the blast. The workmen should take care that no metal remains in the corners of the hearth. By degrees, the cinder will subside, and the iron will become a pasty, tough mass. If it is very hard, and feels like lead, the blast is increased, for a strong heat is required to weld this tough mass into a ball. By continually raising and turning the iron, it will become uniformly heated. When it becomes tenacious, it may be removed to the hammer or squeezer, and reduced to a rectangular prism five or six inches square; and if too long, it may be cut into pieces not exceeding in length fifteen or sixteen inches. These prisms form the blooms of our markets, and are usually sent to the rolling mills to be transformed into bars, or, generally, into sheet iron or boiler-plates.

The cinder in the hearth, unless present in too large quantity, which is seldom the case, may be suffered to remain. When the scraps of iron are removed, and the lining of the hearth secured, and, if necessary, repaired, coal may again be filled in, and the blast turned on.

White iron, and even mottled iron, very seldom boil; but, by proper treatment, arrive as a pasty mass at the bottom of the hearth. This mass should be broken up, and brought, to a greater or less extent, within the range of the blast. But this manipulation requires caution, where we have to deal with white anthracite iron, because this metal commonly works too fast, and, if this propensity is favored, bad iron results. Taking

* Boiling is due to the escape of CO, the oxygen uniting with the C to form CO and CO² according to condition of union.

care to prevent the iron from touching the tuyere, we should keep it in a pasty state as long as possible, to afford the impurities an opportunity of combining with the cinder. When the bottom of the hearth is very cold, it is possible that the metal may be gray or fusible, though the part which touches the hearth may be hard and cold. In this case, the iron, whether in mass or in pieces, should be carefully brought above the tuyere, and once more melted down. In the meantime it is advisable to discontinue the cooling of the bottom-plate.

g. The tools required at the blomary fire are very simple. A few implements like crowbars; several pairs of tongs for lifting the bloom from the fire; and a couple of chisels shaped like hatchets, for cutting blooms, are all we require. Of the means employed to reduce the balls to a proper size, we shall speak elsewhere.

h. The results and the expense of this branch of iron manufacture of course vary greatly. One kind of metal will yield ninety or ninety-two per cent. of blooms; while another kind will yield but eighty per cent., or even a less percentage than that. The same difference may be observed in relation to the quantity of fuel required. The number of bushels of charcoal varies from 150 to 250 per ton of blooms. A blomary fire, conducted night and day for a week, furnishes from four to seven tons of blooms. Wages of workmen from six to seven dollars per ton.

At various places, hot blast is applied with success; but at other places, with but little advantage. In most instances it is not employed.

In Europe, the varieties of blomary fires, or refineries, are innumerable. These varieties depend, in a greater or less degree, on the nature of the coal and iron used, and upon the habits of the people. Many arrangements produce better iron than that we have described. But the advantages which these possess depend upon circumstances which are not available in the United States. The only ore which does not follow the general rule of the oxides and hydrates is the magnetic ore of the different States. This ore might be made to produce as

good iron as the best Swedish. But our furnace owners, in their inconsiderate eagerness to realize every possible advantage, often produce a metal whose quality cannot be at all relied on. Our forge owners, therefore, when they desire a good article, are generally compelled to do the best they can in relation to economy of fuel.

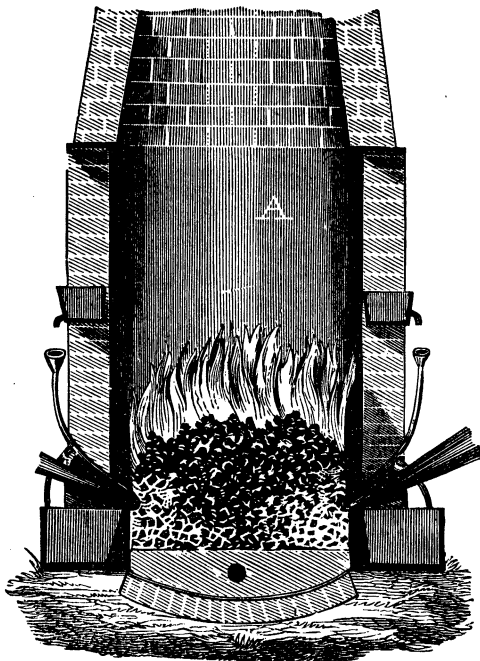
IV. *Finery Fire.*

We shall now describe a process intermediate between the blast furnace and the forge; that is, the *finery* or *run-out* fire. A description of this should have followed that of the blast furnace; but as it is of a later origin, and will, besides, be better understood after the explanation of the German finery, we thought it advisable to delay our notice of it. This invention is the result of necessity. The introduction of stonecoal, coke, and hot blast occasioned so much bad pig iron, that some means which should remove a portion of the impurities in the metal before its removal to the charcoal forge or to the puddling furnace were eagerly sought. The necessity of an intermediate process will be readily admitted: but a more awkward and unprofitable invention than that we are considering could not have originated from the most unskilful intellect. The apparatus is so worthless as scarcely to deserve notice. In fact, when we see the large amount of iron which is converted into slag; when we see the best charcoal iron wasted by the Western manufacturers, we are justified, we think, in wishing that the apparatus had never been invented. But the invention exists, and there is no immediate prospect of getting rid of it; therefore it is our duty to record its existence, and to exhibit its construction.

Fig. 156 represents a vertical section, and Fig. 157 a ground-plan of a finery. It is erected on a platform of brick, about twenty inches in height, in the middle of which is the hearth or fireplace *A*. At each of the four corners an iron column is erected, upon which a brick chimney, two feet in width inside, is built. This fire generally works with four tuyeres, that is, two on oppo-

site sides; or with four nozzles, and but two tuyeres, on the same side. When the latter is the case, two currents of blast are conducted into each tuyere, that the whole surface of the metal may be exposed to the action of the

Fig. 156.

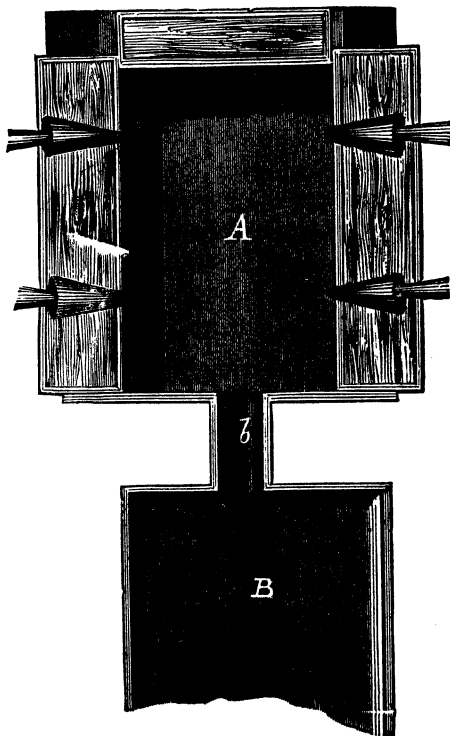


Finery, or run-out fire.

blast. The sides of the hearth are formed of hollow cast-iron plates, through which a current of cold water is constantly running, to prevent their melting. The hearth is generally from three to three and a half feet in length, twenty-four inches in width, and twenty-four or thirty inches in depth. Around the fire are sheet-iron doors, fastened to the columns; these are alternately used to prevent the disturbance occasioned by strong draughts of wind. Such fires produce a great deal of dust, heat, and rubbish, and are generally removed from the main buildings. The bottom of the

hearth is formed of coarse sand, and often of coke dust. The nozzles *a a* are from an inch to an inch and a quarter wide. The blast, of which about 400 cubic feet per minute are required, is produced in iron cylinders. In

Fig. 157.



Ground-plan of a finery.

a prolongation of the tapping hole *b*, is the chill mould; this is a heavy cast-iron trough, sufficiently large to receive the contents of the hearth. It is commonly ten feet in length, thirty inches in width, and four inches in depth. A current of water is led around it to keep it cool. Pipes, sufficiently large for throwing a strong current of water upon the hot iron, should be at our disposal at all times.

When the hearth is ready for operation, fire may be

placed on it, and coke, or, as in many instances, charcoal thrown on; the blast is then applied, and pig iron, to the amount of five or six hundred pounds, charged at once. If the iron is very gray, a greater dip of the nozzles and of the tuyere is given; this secures stronger blast upon the metal, which, after being charged, soon comes down. When the iron disappears from the top, another charge is given, and melted down, care being taken that the coke is duly supplied. In this way, twenty pigs, or generally one ton of iron, are melted. Some time is required, where the iron is gray, before the metal can be let out; and when sparks of burning iron appear to be thrown off from the top of the coke, this time is supposed by the workmen to have arrived. After the lapse of about two hours, the time required for one heat, the tapping hole is opened, and the iron runs into the chill mill mould, or, as it is called by the workmen, the pit. This mould has been previously washed with a thin clay solution, to prevent adhesion of the refined metal to its surface. Cinder also flows off with the iron. As soon as the metal becomes solid, a strong current of cold water is permitted to flow upon it, the reason for which we shall explain in another place. In the meanwhile, fresh coke and pig iron are charged, and the process continued as before.

a. The quality of the refined iron depends principally upon that of the pig metal; while the quality of the latter depends upon the previous manipulation in the blast furnace. Good soft gray or white iron generally furnishes metal of excellent quality; but white, hard, and brittle pig is very little improved in the finery. There have been cases in which 2300 pounds of pig produced a ton of metal; and we have known instances in which 3000 pounds of coke iron were used to produce the same amount. It is beyond human skill to suggest any method by which a waste of iron, to a greater or less degree, can be prevented.

To what extent this kind of work answers its purpose as a forerunner of the finery forge and puddling furnace, we shall investigate at the close of this chapter.

Some years ago, Mr. Detmold, of New York, introduced an improvement upon this mode of refining. He constructed a reverberatory furnace, resembling in form the puddling furnace. The pig iron was melted on a large hearth, and the blast thrown upon its surface to whiten it. But there is little merit in either of these refineries.

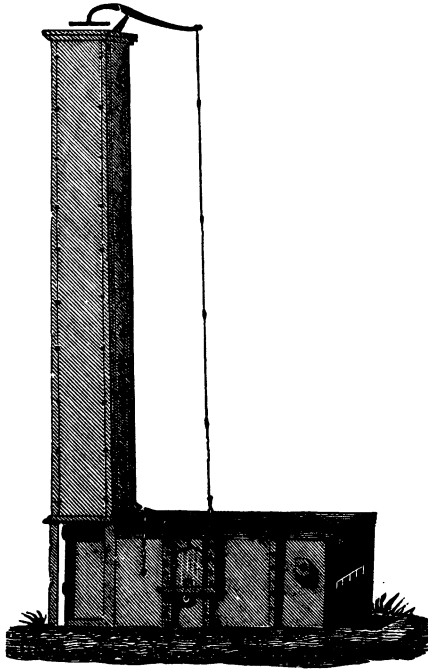
V. Puddling Furnaces.

The reverberatory or puddling furnace is, unquestionably, of all arrangements, the best adapted to convert cast iron into bar iron. The imperfect results which have hitherto been obtained with respect to the quality of iron, have, as might have been expected, depended upon a variety of circumstances. We shall endeavor to give a clear and comprehensive insight into the whole manipulation, practically and theoretically.

a. At Pittsburg, and throughout the West, the single furnace, and on the eastern side of the Alleghany Mountains the double furnace, are generally employed. The former is the most ancient form of the puddling furnace. Fig. 158 exhibits a side elevation of such a furnace, including the stack. It represents the work side at that point of view from which the door to the interior can be seen. The stack, or chimney, is generally from thirty to forty feet in height, and erected upon a solid foundation of stones; this foundation is covered with four, or, in many cases, with but two cast-iron plates; upon these plates, four columns of cast iron are erected, forming four corners of the chimney. A square frame, formed of four cast-iron plates, is laid upon these columns; and upon this frame the chimney is erected. The exterior or rough wall of the chimney, width nine inches, is made of common brick, and well secured by iron binders, which are generally flat hoops, from one-eighth to three-sixteenths of an inch thick. These hoops occupy no more space than a layer of mortar; and they should be placed at intervals of two or three feet, or sometimes of

even three or four feet, while laying the brick. The binders, into which an oblong hole should be made,

Fig. 158.

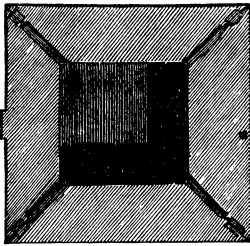


Elevation of a puddling furnace.

should overlap the brick about two and a half inches; through this hole a bar three-fourths of an inch square may be pushed. Two of these upright bars, which should extend the whole height of the stack, are required at each corner. The top of the chimney is covered with a cast-iron plate; but this is sometimes dispensed with. Such a top-plate is a useful appendage, for it secures the bricks; but, if not properly made, it is troublesome; it is apt to break into halves, and fall down, under the influence of heat. To prevent this accident, it is advisable that the top-plate should be formed of four pieces screwed together; the points in the corners should be left open,

to give room for expansion from the centre of the plate. Fig. 159 represents such a plate from above, and Fig.

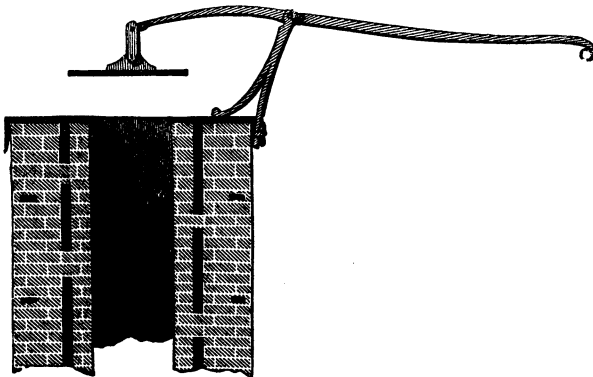
Fig. 159.



Plan of a chimney top.

160 in a vertical section, with a portion of the brickwork of the chimney. The interior of the stack should be built of good fire-brick; for single furnaces sixteen, and for double furnaces from eighteen to twenty, inches square. The frequent expansion and contraction of this lining under a high heat affect its durability. A space of an inch or an inch and a half, left between the rough wall and the in-wall, with a brick occasionally projecting, will, to a great degree, prevent contraction. Fig. 160 exhibits the arrangement of the in-wall and rough wall distinctly. A wire reaches from the damper on the top to the side of the furnace, the most convenient place for the workmen.

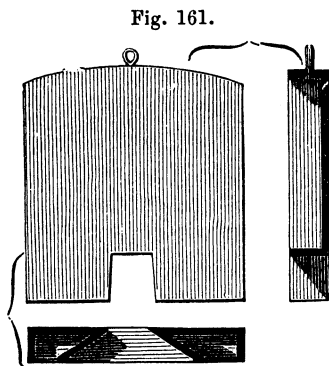
Fig. 160.



Chimney top.

b. The exterior of the furnace, eleven or twelve feet in length, about five feet in height, is composed of cast-iron plates. Into the small square hole, coal is thrown. The large one is a sliding door for the charge and dis-

charge of the iron; the hole in this door is designed for the introduction of the tools. The door is suspended on a chain, fastened to a lever, which is above the head of the workman. Fig. 161 represents the door on a large scale, in which a front view, a vertical and horizontal section, are shown. The average size of this door is twenty-two inches in width, and twenty-seven inches in height. Its inside towards the fire is filled with fire-brick, tightly wedged in. The square work hole is very much sloped inside, to enable the workman to reach every part of the furnace hearth.

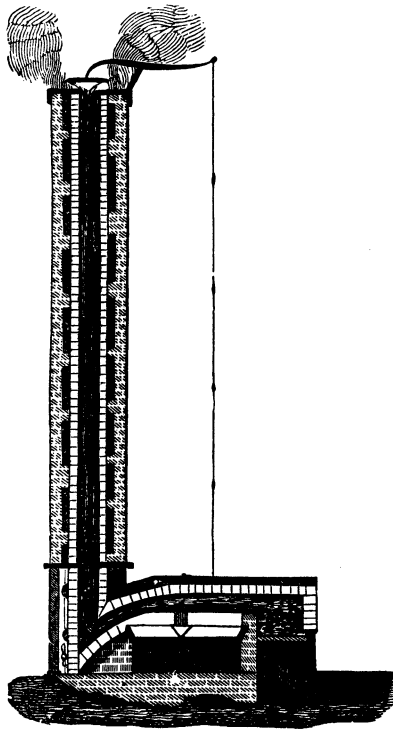


Door of a puddling furnace.

Fig. 162 exhibits a vertical section of the furnace and the stack. The whole arrangement is a judicious one. The structure is built of fire-brick and common brick; the former is indicated by the lighter, and the latter by the darker, shade of lining. The fireplace on the right hand is a separate chamber, designed for nothing else than the combustion of fuel. Behind the fireplace, *i. e.*, to the left of the fireplace, is the hearth, where the iron is charged, melted, and puddled. The hearth is heated in part directly by the flame, but chiefly indirectly by the reflected heat from the roof, for which reason this furnace is called a reverberatory furnace. For western bituminous coal, a grate measuring three by two feet is sufficiently large; but for anthracite coal, a much larger grate is required. The hearth is five feet, sometimes six feet in length, and three and a half or four feet in width, and of an irregular form. Its bottom and sides are made of cast iron, and prevented from melting by a constant current of cold air. Formerly, where this was not sufficiently strong, a dish of water was sometimes thrown under the bottom. By care on the part of the workman, the application of water was unnecessary. If the bottom

plates are so thin as to be in danger of bending, they should be supported by props made of iron rods.

Fig. 162.

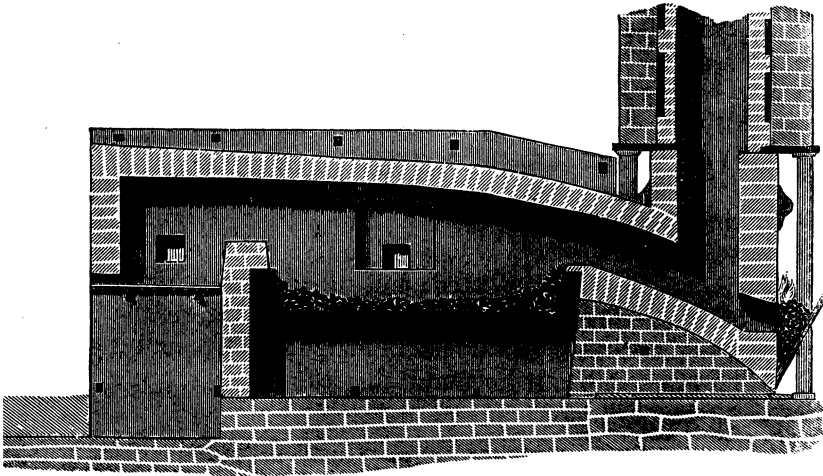


Vertical section of a puddling furnace.

After heating the hearth, the flame is conducted through the inclined flue into the stack. The size of the flue depends on that of the hearth, and upon the interior dimensions and height of the stack. A flue ten by twelve inches square is considered to be sufficiently large for a single furnace. A large hearth with a narrow and low stack requires a larger flue than a small hearth with a high or wide chimney. The dimensions of the grate increase with the incombustible, and decrease with the inflammable, nature of the fuel we employ. A grate measuring one square foot is large enough for dry wood; while for anthracite coal a grate of twenty

square feet is required. Behind the furnace, on one side of the stack, a small fire is seen burning. This fire is to be kept up at those furnaces where the fire-bricks produce cinders, or where the slag from the furnace hearth passes the flue bridge. The accumulation of cinder obstructs the passage of the flame; and a small fire at the flue, with a slight draught into the chimney, keeps that part of the furnace sufficiently warm to prevent such accidents. Fig. 163 represents a section of a

Fig. 163.



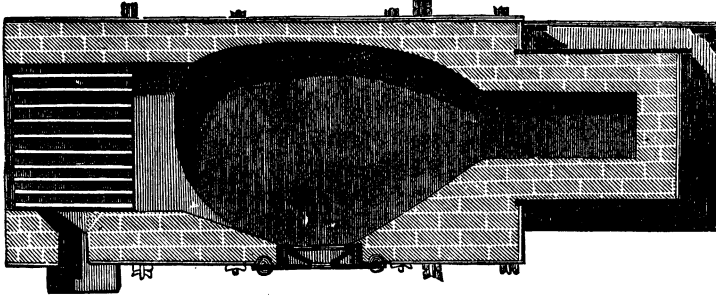
*Vertical section of a single puddling furnace.

furnace on a larger scale than the above; the furnace also is shown more distinctly. The ground plan of this furnace is exhibited by Fig. 164, in which the form of the hearth, the plan of the fire chamber, grate, and the fire bridge, are clearly shown. In these illustrations, the cast-iron plates which inclose the hearth are also clearly shown. These plates, about ten or twelve inches high, are made to cross the bridges, as well as to secure whatever else needs security.

c. The process consists of puddling and boiling. Puddling is very nearly the same thing as boiling, with slight differences in manipulation. In puddling, metal

from the run-out fire* is worked, and sometimes mixed with good white charcoal metal from the blast furnace.

Fig. 164.



Ground-plan of a single puddling furnace.

In boiling, the gray or mottled pig iron is brought directly to the furnace, and refined by means of slag; this iron, in the course of the manipulation, rises along with the cinder, and its motion is like that of boiling water. The latter process would, of course, be the more profitable, if generally effected; but on account of cinder, there is a limit to the boiling operation. Therefore, in a rolling mill forge, half the furnaces are sometimes employed for boiling, and half for puddling; the latter supplies cinder for the former.

d. The process of operation, in these furnaces, is as follows: A new furnace is dried slowly; that is, a small fire is put in the grate, not quite filled with coal. This fire is usually kept up for three or four days. After the furnace is dry, which is indicated by the cessation of vapors from the brickwork, the grate is cleared from clinkers. A good stonecoal fire is then kindled, which, in the course of four or five hours, will bring the furnace to a heat proper for charging the metal. Previous to this, the iron bottom of the hearth is covered with finely pounded cinders from a charcoal forge, or from another puddling furnace, or from a reheating furnace. If none can be obtained, cinder from a blast furnace will answer. This cinder is broken into uniform pieces

* Metal run melted into the puddling furnace.

of about an inch in size. A portion of it is thrown around the sides and bridges, and covers the bottom to the height of three or four inches. Fire should then be applied to the cinder for about five hours. By pounding it, when it gets soft, so as to fill all the crevices, the cinder will not only melt more readily, but the furnace will become more thoroughly heated. A perfect fusion of the cinder is required before iron is charged, otherwise, it will not form a solid lining over the iron plates and bottom. But for this object alone it is employed. If crevices are left in the cinder, drops of melted iron will find them, and penetrate to the iron bottom of the hearth. Thus the thickness of the bottom is not only unnecessarily increased, but it is made rough, and occasions troublesome manipulation; besides, a portion of the iron is lost. When the cinder is melted, and the bottom and sides properly protected, the door is lifted, and cold cinder mixed with the melted mass. When the bottom is so far cooled that the tools make no impression on it, the metal is thrown in, the door shut, and the fire brought to good order. The door, which, as shown in the drawing moves in a frame, is fastened by two wedges, one on each side. These wedges are driven in between the frame and the door; for which reason, the door is about an inch smaller than the frame. Fine cinder, or hammer-slag, is thrown around the door, to prevent a draught of cool air through the crevices. In the work hole a piece of coal is laid, covered by a small plate of sheet iron. Meanwhile the door is secured by the puddler, and the helper charges coal, cleans the grate, and heats the furnace as strongly as possible. Within a quarter of an hour, the iron, in some places, begins to get red; the helper then takes a bar, introduces it through the hole in the door and turns the iron, that is, he moves the warm iron to a cold, and the cold iron to a warm place; after which a fresh charge of coal is supplied. Within half an hour, if everything is in good order, the metal becomes white, and ready to melt, when the helper, by means of a hook, breaks the pieces, and mixes the iron with the half liquid cinder; at the

same time, the puddler stirs the grate, with the object of augmenting the heat. In forty-five minutes the iron may be brought under the protection of the cinder. At this point, the divergence in the manipulations of puddling and boiling commences. We shall first speak of puddling; but, preliminary to this, we shall describe the tools applicable to this process.

e. Most of the tools consist of iron bars and hooks. Five or six are required at each furnace. Fig. 165 represents a bar from five to six feet in length. One end of it is sharpened and square; the other end terminates in a round knob, which enables the workman to handle it with facility. The lengthier portion of the bar and

Fig. 165.



Puddling bar.

hook is eight-sided, for a bar of this shape is held more firmly than one that is round. These tools suffer greatly

Fig. 166.



Puddling hook, or rabble.

from the heat of the furnace, particularly when used for too long a time at once by careless workmen. The heat is apt to slit and break the iron. For this reason, charcoal forge iron is preferable to puddled iron for tools. A water trough, six feet in length, twelve inches in depth, and fifteen inches in width, is attached to each furnace. This trough should be constantly supplied by a stream of cold water, to cool the heated tools. A large pair of tongs is also required to grasp the hot balls in the furnace. These balls are either dragged on iron slopes to the hammer or squeezer, or, as is more commonly the case, they are loaded on iron wheelbarrows, or carriages, made expressly for the purpose, and wheeled by the

helper to their appropriate destination. A flat bar, with a round handle, for stirring the fire, and cleaning the grate; a coal shovel; a small hammer; and an oblong, sheet iron dish for throwing water or hammer-slag in the furnace, complete the list of implements requisite at a puddling furnace.

f. When the metal is heated to such a degree that a blow from a hook will break it, the damper should be lowered. If the iron is not of the best quality, the damper should be very nearly closed, so as to prevent the access of oxygen until the metal is thoroughly mixed with the cinder. By this means the iron is protected, time is given to the workman to break it, and an opportunity afforded for a combination of the impurities with the cinder. Where the metal is of good quality, so much attention is not required at this stage of the process. When the iron is well worked into the cinder, the damper may be slightly raised; and if but little flame is in the furnace, a small quantity of coal may be thrown into the grate, and the fire stirred. At this point the duties of the assistant workman cease. The puddler, then, with a good sharp bar, frees the bottom and sides of the furnace of any lumps of metal, or lumps of iron already refined; and in case the bottom is not perfectly smooth, he takes away the projecting parts, which are generally metal, adhering to the cinder. Gradually, the mixture of iron and cinder rises spontaneously, and exhibits a kind of fermentation. This may be kept down by raising the damper; or, by stirring the fire, it may be permitted to rise still higher. If all the iron is melted, and the furnace in good order, the rising must be prevented; but if the furnace is not quite clean, it is preferable to maintain a low temperature until all the iron is mixed in small particles with the cinder. When this is fairly accomplished, the damper may be slightly raised, so that, in addition to the heat, a small quantity of oxygen may pass through the iron. Should the metal have been of good quality, but little time is required to separate the iron and cinder; this stage of the operation is called *coming to nature*, and is charac-

terized by the iron forming at first small, and to all appearances round particles of the size of peas, which swim in the cinder. When these particles of refined iron begin to grow larger, by adhering one to another, the damper may be raised, and the heat in the furnace brought, by degrees, to the highest point. The accumulation of the particle then proceeds rapidly. Active manipulation is required to prevent the formation of too large masses. By breaking up and turning, the whole mass is uniformly heated. After a short time, by squeezing the small lumps, by means of the bar or hook, round balls, twelve or fifteen inches in diameter, or seventy or eighty pounds in weight, are formed. After all the balls are finished, the work is shut for a few minutes, that a final and thorough heat may be given to the iron. When this is accomplished, the wedges at the door are loosened, the door is lifted by the helper, and the puddler takes one ball after another to the hammer or squeezer, or loads it on an iron hand-cart, which the helper wheels to its place of destination.

g. If the metal charged is gray or mottled, a somewhat different method of working it is pursued. So far as the heating of the iron is concerned, but little difference in the treatment is required, though the heat, before commencing operations, must be stronger than in the puddling process. It requires some skill to hit the proper time for commencing operations. If we commence too soon, the iron will divide into small particles, and assume a somewhat sandy appearance; in this case the work will not only proceed slowly, but the iron will be of inferior quality. If, on the other hand, the metal is melted perfectly, the result will be rapid work, and an excellent quality of iron. Melting of the metal may be accomplished by leaving the damper open until the iron and cinder have become sufficiently liquid, after which it must be shut to exclude atmospheric air. At this time the interior of the furnace appears dark and smoky, and black fumes issue from the almost closed top of the stack. The melted mass is continually stirred, and at intervals of a few minutes, fluxes, consisting of hammer-slag, or

pounded ore and water, are applied. If these act their part well, the surface of the mass will be covered, to a greater or less extent, with blue flames. Within twenty minutes the cinder commences to rise; a kind of fermentation takes place beneath its surface; and the mass, at first but two inches high, rises to a height of ten or twelve inches. Whilst the cinder and iron are thus rising, constant stirring is required to prevent the settling of the iron on the bottom, which is now deprived of the direct influence of heat. If the process goes on well, no iron is yet visible. When the cinder rises to its proper height, the duties of the helper cease. The puddler then commences, by means of a sharp bar, to free the bottom and sides of the furnace of lumps of metal. At this point the damper may be slightly raised; and, by the addition of a small quantity of coal, a bright flame may be produced. Soon after this, the iron is seen in small, bright spots at the surface of the cinder, and then alternately appears and disappears. Brisk stirring at the bottom and at the sides is now requisite to prevent the iron from remaining at the cold bottom, after having once been at the surface. The iron and cinder, when in lively motion, have a striking resemblance to the boiling of corn; from this resemblance the term *boiling* is derived. At a well-managed furnace, the boiling lasts about a quarter of an hour; the cinder gradually sinks; and the iron appears in the form of porous, spongy masses, of irregular size, which are to be stirred, to prevent their adhering together in lumps too large to be formed into balls. At this stage of the process the heat should be raised as high as practicable. The iron, even in its spongy form, will be quite hard, and a good heat is required to soften it sufficiently for welding. If the heat is not strong, the iron is not apt to stick; and if put together by squeezing, it will not bear shingling; besides, the balls are likely to break under the hammer, or in the squeezer.

The method of removing the balls is the same as that before described.

Puddling and boiling differ mainly in the method of

bringing the iron to nature; that is, producing that transformation of metal which constitutes bar iron. The difference between white and gray iron does not produce the difference in the work, but the degree of fusibility of the iron, and the time required to crystallize it. The description we have given of boiling and puddling applies only to cases in which good wrought iron is produced. Instances occur in which both processes are applied in the same case; and we think we shall but slightly err if we state that the puddling operation is generally conducted, to a greater or less degree, to a state of boiling.

h. The construction of boiling and puddling furnaces does not vary materially except in the depth of the hearth; that is, in the distance from the work-plate below the door to the bottom plate. In the latter, a depth of six inches is sufficient; while in the former, a depth of eleven or twelve inches is required. In the puddling furnace, the distance between the bottom and top seldom exceeds twenty inches; in the boiling furnace, it varies from twenty to thirty inches. In the former, the iron boshes do not always reach all round the hearth, but are frequently confined to both bridges; in addition to which the sloping sides are of fire-brick.

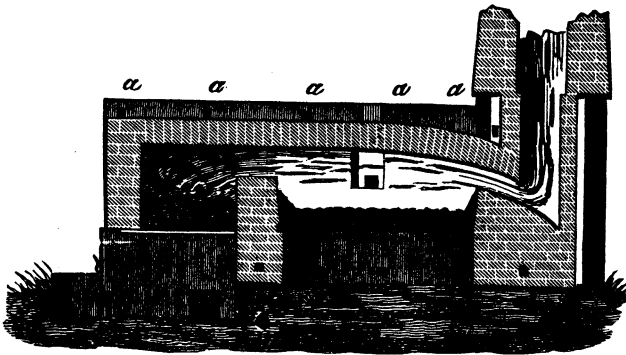
i. In puddling, the furnace is charged with metal alone; but in boiling, cinder is charged along with the metal. When the balls are removed from the boiling furnace, a large mass of fused cinder remains in the bottom, a part of which is let off, through the tap-hole below the work door, into a two-wheeled iron hand-cart. A small portion of the liquid cinder is left in the furnace. A large quantity of cold cinder, from the hammer or squeezer, is now thrown upon the pasty cinder; and upon this cinder the pig metal is placed. The cinder which results from boiling is of inferior quality, but it is improved when mixed with that from the puddling furnace. For this reason, puddling furnaces are used at the western puddling establishments. Charcoal forge cinder, added to the above hammer cinder, is still better than that from the puddling furnace.

At the Pittsburg works, it is customary for the puddlers to make six, and the boilers to make five heats in a turn, of a charge weighing 350 pounds. This is accomplished in eight or nine hours. The workmen make but two turns in twenty-four hours; therefore an interval of six to seven hours, during the night, is left, in which the furnaces are stopped up. The workmen change every day at twelve o'clock; the first set begin at three or four o'clock in the morning, and the second cease at about ten at night.

k. The construction of the western puddling furnaces does not differ materially from that of the single furnace generally in use in England; but they are distinguished by iron boshes, by which the hearth is lined all around, which is not the case anywhere else in single furnaces.

In the Eastern States, there are single puddling furnaces in use. Where anthracite is employed, the construction of the fireplaces is modified. The following illustrations will serve the purpose of description: Fig. 167 represents an anthracite furnace dissected vertically

Fig. 167.



Puddling furnace for anthracite coal.

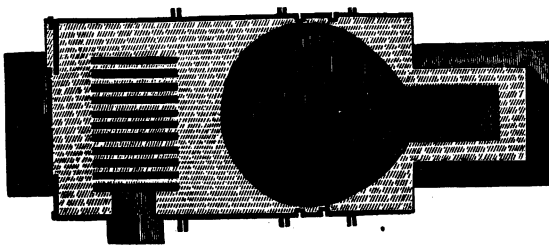
through the grate, hearth, and chimney. The arrangement varies but slightly from that of the single furnace we have already described, with the exception that the grate is deeper. In this furnace, coal can be filled to the depth of twenty to twenty-four inches; while, in the

bituminous coal furnace, a depth of ten or twelve inches is sufficient. The cross binders, which we omitted to mention in our description of the single furnace, are marked *a a*. These binders are a necessary element in the construction of a furnace. They are wrought-iron square bars, either with screw and nut, or with a key, and serve to bind together the cast-iron plates of the inclosure. They prevent the sinking of the roof caused by the expansion and contraction of the fire-brick. The two holes below the grate serve for the passage of the blast. For this purpose, one orifice is usually deemed sufficient. The blast machines are fans; and, as pressure of the blast is unnecessary, they serve every purpose. We have spoken of these in another place.

The incombustibility of anthracite coal makes the application of blast necessary. A chimney cannot draw through a high column of coal an amount of air sufficient to give it the requisite heat. If the column of coal in the grate is left low, all of the oxygen of the air is not absorbed, and the quality of the heat is impaired. Anthracite can be most successfully burnt, when blast is applied to it.

Fig. 168 exhibits a horizontal section of the double furnace. The hearth and grate are seen from above.

Fig. 168.



Anthracite double puddling furnace, horizontal section.

In a double furnace, the grate commonly measures three by five, and in a single furnace, three by four feet. The width of the furnace externally is from five and a half to six feet. Some furnaces measure even seven feet; but

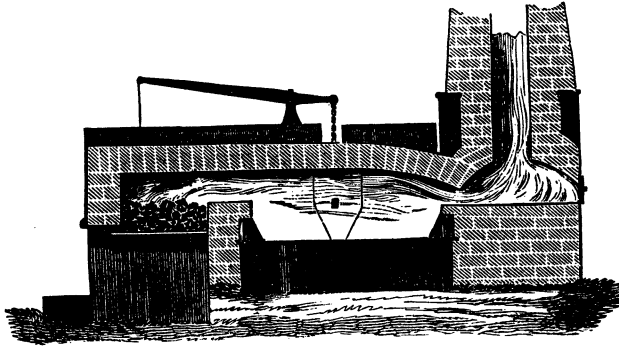
this is rare. The hearth is generally six feet in length, and its width accords with that of the furnace. The flue ought to measure at least 150 square inches; and more than that, if the chimney is narrow. However, a flue twenty-four inches in width, and seven inches in height, may be considered of good size. The chimney is sometimes of larger dimensions than necessary. A lining sixteen inches square is sufficiently wide for a double or single furnace. A chimney high enough to carry the hot gases out of the furnace is, under all circumstances, sufficient. The draught, and consequently the heat, depend upon the blast, for which reason it matters very little what kind of chimney is employed.

The main difference between the double and the single furnace is, that in the former there are two work doors, one directly opposite the other. Therefore, two sets of workmen are required at the same time. In this furnace, double the quantity of metal is charged, and of course the yield is twice that of a single apparatus. The advantages of this arrangement are obvious. Rooms, building expenses, and fuel are economized, and much of the labor of the workmen saved. Besides, but one good puddler is required for managing the operation; while at a single furnace two are needed. Of course, no more repairs are required for one furnace than for the other.

The arrangement of the hearth in a double furnace varies considerably. In Pennsylvania and the anthracite region, the boshes are made of soapstone, a refractory material found in Eastern Pennsylvania and New Jersey. In some places, they are made of a refractory ore, magnetic oxide, mixed with soapstone. In the State of New York, and the New England States, the furnaces are provided with hollow iron boshes; and where anthracite is employed, the blast is led through these boshes, and the air, thus heated, applied to the coal. In many cases, where the boshes are of iron, iron ore is used, partly to protect the boshes and partly to flux the iron. On the Hudson River, the crystalline magnetic ore from Lake Champlain, an excellent article, is em-

ployed for this purpose. The following illustration (Fig. 169) of the cast iron hollow boshes will be understood without any description. Their height is usually

Fig. 169.



Double furnace with air boshes and heating stove.

from twelve to fifteen inches; their width at the bottom six, and at the top from three to four inches; the inside slopes toward the centre. These plates are generally so arranged that the whole is cast in two parts, and divided at the doors. Each part forms a bridge, and its two wings serve to form the sides.

There is no difference between the manipulations at this, and those at the single furnace. It can be used either for puddling or for boiling; or, at least, a process analogous to boiling. That is to say, the fermentation is carried to half the extent of that usual in regular boiling. At one time, this furnace labored under a serious disadvantage. The quantity of iron it would prepare at once, sometimes amounted to 900 pounds. Therefore, the time necessary for shingling so large an amount at the hammer, or the old-fashioned squeezer, was not only injurious to the iron, but occasioned a loss of time to the workmen. This difficulty is at present effectually removed by Burden's rotary squeezer.

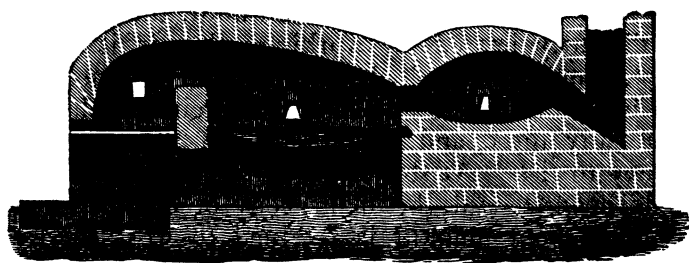
l. At some Eastern establishments, the heating stove is applied to the puddling furnace. It forms an appendage or prolongation of the hearth. Its location is generally between the pillars of the stack. It is charged

from behind, and on this account is very convenient. Fig. 169 shows the arrangement of this stove. With experienced workmen, it affords facilities for economizing fuel and time; but with awkward workmen, it is of doubtful utility.

Before we give the general practical rules which should guide us in our manipulations, we shall present two very interesting illustrations of puddling.

m. Fig. 170 represents a section of a single furnace in operation at Hyanges, France. The general appearance

Fig. 170.



Single puddling furnace at Hyanges.

of this resembles that of any other puddling furnace, with the exception of the manner in which the heating stove is applied. In this instance, it forms a prolongation of the hearth, while the flue is behind it, leading to the stack. Bituminous coal is used, and the grate is constructed in accordance with this circumstance. Thus far there is nothing unusual in this furnace. Its characteristic feature is, that its bottom is of cast iron, which is from four to five inches thick. The fire bridge is about six inches high; the flue bridge, formed by the stove, is of the same height. At the centre, the bottom is four inches deeper than at the sides, and is about four and a half feet in width by five in length. It is secured from below by iron props, and therefore, when burnt or cracked, may be replaced by a new one.

In this furnace, the worst kind of coke iron is converted into fibrous bar iron of very fine appearance; but for the blacksmith's use, this article is of poor quality.

To those manufacturers who desire to produce cheap iron, with no special regard to quality, this furnace is worthy of imitation. The pig iron of Hyanges is smelted from a brown, fossiliferous ore resembling the fossiliferous ore of Eastern Pennsylvania. It is run into large chills, directly from the blast furnace, and cooled off as at a running-out fire.

After being properly heated, the furnace is charged with a small wheelbarrowful of hammer cinder, mixed with pounded feldspar. The metal in the stove, previously charged and red-hot, is drawn by the puddler upon the cinder. The furnace is then closed, and a good fire prepared. Within a quarter of an hour, the metal will be sufficiently heated for working; that is, it will be red-hot, though not melted. The puddler commences to break up the iron, and mix it with the cinder; the mass is gradually fused and the cinder and iron exhibit a tendency to rise. At this stage of the process the tap hole is opened, and the main body of cinder let out. Only a sufficient amount is retained to work the iron. In the mean time, a good fire is prepared; and the puddler draws the damper rod as soon as the cinder has flowed out. The refuse cinder is then covered with ashes, and the operations vigorously prosecuted. If well conducted—and this consists only in quick work, for the iron comes to nature when the surplus cinder is gone—the whole process will be completed in an hour. When the balls are finished, and the door closed up for a final heat, the metal is charged into the stove, after which it is drawn and shingled. The process is then again commenced, and continued as before.

At this furnace, but one workman is required at a time. A heat is commenced and finished by one man, without any help; the next heat is worked by another puddler. Some workmen employ a boy for stirring the fire; but this is not always the case, for the boy must be paid from their own earnings. At the time we visited the works at Hyanges, 250 kilogrammes (equal to 550 pounds) formed a charge; and nine or ten heats were made in twelve hours, the workmen changing, however,

at every six heats. With four workmen, a single furnace furnished from twenty to twenty-five tons of iron per week; a great deal of which time was consumed in shingling the balls. By the use of Burden's squeezer, thirty tons per week could be produced. The manipulation at the Hyanges furnaces differs from that at common furnaces in the fact that the puddling is done on a red-hot iron bottom, as well as in the fact that a feldspar flux is added to the cinder. In another place, we shall investigate the reasons why this process differs so materially from the common puddling operations.

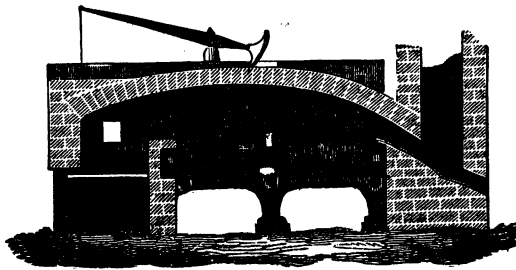
n. During a period of three or four years, we were placed in a position which required the highest degree of perseverance. We engaged in the most difficult enterprises, with the object of improving the puddling operations; sometimes with success, and at other times failing to accomplish what we had proposed to ourselves as the result of our labors. The results of the experience thus acquired, it is our purpose to relate, with the hope that they may prove useful to those engaged in this difficult department of labor.

In the years intervening between 1832 and 1836, great exertions were made by iron manufacturers to improve the quality, and to increase the quantity, of iron, by means of artificial fluxes. It was already a matter of conviction amongst educated metallurgists, that the quality of the metal in the furnace depended upon the accompanying cinder. The conclusion very naturally followed, that, if we could prepare a cinder of given quality, the desired metal might be obtained with comparative ease. However true the fundamental premise may be, the sequel proved either that the conclusion was only measurably true, or that a cinder answering, in every respect, our wishes, remained yet a desideratum. In the investigation of this subject, numerous experiments were made, in which we participated. In applying the artificial composition of cinder to the puddling furnace, subsilicates of such remarkable fusibility resulted, that the best fire-brick was, after a few heats, entirely destroyed. But a settled conviction was arrived

at, that the injurious admixtures of a metal no longer formed an obstacle in furnace operations; for phosphorus, sulphur, and silex were so completely removed from the iron, that no difference appeared to exist between the best and the worst metal. On the contrary, there was reason to believe that the advantage was on the side of the inferior metals. How far the latter conclusion is true, we shall hereafter see. In consequence of the destruction of the hearth, we lined the furnaces with cast iron, wrought iron, and other refractory materials; but all to no purpose. The uniform result was that the cinder was either too fusible, or that the iron manufactured was so hard and tough as to require a heat which no lining could withstand. After innumerable experiments, we succeeded in constructing a double furnace with water boshes. At first, this answered every purpose; but how it succeeded where we had to deal with different metals, we shall relate in another place. Nevertheless, from the construction of that furnace, the principle was established which, with proper modifications, is applicable in all cases. As this principle was the basis of all subsequent modifications, and as it was extensively adopted throughout the Continent of Europe, we shall present an engraving of the furnace, and notice in another place the alterations which it has since received.

Fig. 171 represents a vertical section of the double

Fig. 171.

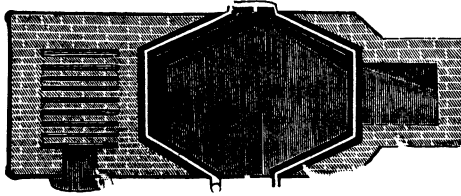


Double furnace with water boshes.

furnace. The boshes are heavy cast-iron plates, ten inches high, five inches thick, and with a small passage of about

an inch or an inch and a half bore. They extend all around the hearth, being coupled at one door. At the

Fig. 172.



Ground-plan of a puddling furnace with water boshes.

other, the water has entrance and exit. But very little water is required to keep these boshes cool. The bottom of the furnace is formed of small cast-iron plates, about twelve inches in width; their length corresponding with the width of the furnace. The grate measures three feet in width by two feet in length; length of hearth six feet, and width between the doors five feet. Stack forty feet in height, and diameter of lining eighteen inches. Width of flue twenty-four inches; height six. Distance between the iron bottom of the furnace and the brick roof twenty-eight inches. The lower parts of the furnace are open, so as to permit a free circulation of air to cool the bottom.

This furnace works exceedingly well in all cases in which inferior cold or hot-short iron, smelted by heavy burden, is puddled. From any fusible metal, that is, from any metal smelted from a heavy burden, or by low temperature, very superior iron may be puddled by the application of artificial fluxes. Iron equal to the best charcoal iron may be manufactured from cold-short, or from any very fusible metal. But for gray metal of small burden, particularly for all coke, stone coal, or hot-blast iron, these furnaces are of questionable utility. For white metal they are perfectly useless. We failed invariably in our attempts to work white metal of small burden, whether it belonged to the best quality, or whether it was smelted by coke or anthracite, or hot blast.

o. The manipulation in this furnace does not differ from that previously described; but, as the application of artificial fluxes is not practically so well understood, we shall briefly describe it. This furnace is not adapted for puddling, or for the working of white metal, but for boiling alone. It is heated in the same manner as any other furnace. Cinder is filled and melted as described heretofore. At the close of every heat, a portion of cinder is let off, in case too much exists at the bottom. But this is not likely to be the case, if due care is observed. When the cinder at the bottom is cooled off, the metal is charged in the middle of the furnace. This may be taken from the heating stove, in case one is connected with the furnace. Should there be a good fire, it will be ready for work in half an hour, when it may be broken up, and mixed with the cinder. When the pig iron is bad, that is, cold-short or hot-short; or where it contains sulphur, phosphorus, and silex, besides carbon, the fire should be well stirred, without charging fresh coal, and the temperature raised sufficiently high to melt the iron perfectly; otherwise we cannot produce a good article. Whether the iron is melted, and not merely mixed with the cinder, may be known by the formation of bright streaks in it. When the mass is thoroughly liquid, the damper may be almost completely shut; still, the interior of the furnace should be bright, though the flame is not visible. The artificial flux is now thrown into the furnace, at intervals of one minute. Assuming this flux to be divided into ten or twelve portions, all of it may be applied in fifteen minutes. During this application, iron of good quality rises; but that which is bad, or very liquid, rises only by means of hammer slag or water. Before the cinder rises, blue flames, in many cases, literally cover the surface; but cease when the iron comes to nature, that is, shows itself at the surface in little specks. One hour is sufficient for this part of the process, that is, from the charging till the appearance of the refined iron. Some metals work slowly; but this difficulty may be remedied by the construction of the furnace. When the iron is refined,

that is, when it boils strongly, and begins to rise, the damper may be raised, and fresh coal applied. The boiling will thus be brought to a stop. By gradually increasing the heat, working fast, and turning the finished iron, which is now in spongy, open lumps, the cinder rapidly sinks, and the iron is left bare, ready for balling. If the depth of the boiling cinder, at its highest point, is five or six inches, one turning will be sufficient; but if ten or twelve inches, the iron generally becomes so cold in the bottom, that a turning back and forward several times is required. If this kind of boiled iron is balled up cold, it will break under the hammer or squeezer, of whatever quality it may be. The responsibility of this department rests upon the puddler. This process differs from other processes principally in the melting-in of the metal. The more inferior the metal, the more carefully should this be performed.

If the metal is of poor quality, a charge should never exceed 700 pounds; but if otherwise, it may be increased to 800, and even 900 pounds. Bad pig iron, though inclined to work slowly, may be worked quite as fast as that which is good, if the charges are small. The quality of puddled iron may be made equally good under all circumstances. Pig iron may contain phosphorus, sulphur, or any injurious admixture except copper. Puddled iron may be completely freed of them. Bar iron manufactured from the most cold-short gray pig iron which contains phosphorus, may be made superior, in every respect, to that manufactured from the best metal.]

CHAPTER II.

RECENT IMPROVEMENTS IN THE CONSTRUCTION OF PUD-
LING FURNACES—PRESENT PROCESSES AND METHODS
OF REFINING.

AT Catasauqua on the Lehigh, Pa., a water bosh has been added to the furnace and placed immediately at the inner angle formed by the stack and the top of the furnace in the outside. It has been found that there is a very great consumption of the material on inside corresponding with this part of the furnace on the outside, and much delay is caused by the repairing of this part. We are informed by Mr. Oliver Williams, the Superintendent, that since the introduction of this water bosh, at this point, a very large saving has been effected in brick and in the time consumed in repairing.

There is no doubt much practical common sense, and considerable science, to be exercised in the application of water boshes of any kind, as absorbents of heat from these furnaces. Too many and too large boshes of this kind, while they prevent the sensation of heat externally and waste by heat internally, lessen the efficiency of the furnace heat, cause increased expenditure of coal, and delay the proper operation, or destroy the proper effect of heat upon the charge. In all these improvements, therefore, these results are carefully to be guarded against. A very important form of outside lining has been adopted at the Cambria Rolling Mill, Johnstown, at Scranton, Pa., and elsewhere, of semicircular beadings of about $2\frac{1}{2}$ inches diameter, resembling a contiguous series of long half cylinders with alternate concavities and convexities. These semi-cylinders running up and down immediately against the outside lining of the furnace, have a tendency to disperse the radiated heat, making it less disagreeable to the workmen. It appears to us, however, that a better

form might be adopted in a series of vertically and angularly placed slats, whereby the heat might be more effectually deflected from a radiating line immediately in front of the working-door, or better yet, a temporary thin casing raised half a foot from the ground, and two inches off the wall of the furnace lined, if necessary, with a thin coating of fire-clay. This, while it does not lessen the heat in the furnace at all, would, by an ascending current and because of non-conduction, very materially lessen the radiant heat. Experiments upon our suggestion of angular casing (a plan-section being like a series of the letter W, with angles joined thus, WWW) have given satisfaction, but the other plan might be satisfactory. (See Plate at end of this volume.)

The utilization of the waste gases of the puddling furnaces, is a subject of great importance, and one among the most complete plans of construction, taking into consideration all things connected with the furnace, and involving this utilization, may be found at Oxford Furnace, on the Delaware and Lackawanna Railroad, in Warren Co., N. J. Some French engineers, on a visit to this country, expressed themselves so exceedingly well pleased with the plans, that we have given an illustration at the close of this volume from drawings furnished us by Mr. Wm. Scranton, of the Works. We understand that many parts are from suggestions of the able superintendent, Mr. Henry. The furnaces are all single puddling furnaces, and the boilers are flue boilers. Generally that part of the flue which receives the flame is lined a short distance with fire-brick, Plates III., IV. The semi-cylindrical casings are seen represented. A fan is used for blast. We have given these furnaces in detail, as we know of no furnaces in the country superior to these. Mr. Wilhelm, formerly of the Company of Evans & Co.'s Rolling Mill, Phillipsburg, N. J., informs us that from a personal examination of a lining of puddling furnaces, lately invented and applied by a mechanic in New York city, he is persuaded that a great improvement is about to be effected in this important point. The lining, from what we can learn, not having examined

it sufficiently to give our own opinion, is a composition of fire-clay of the best sort, somewhat improved by addition of some other material, perhaps a magnesian silicate, and is put in after the furnace walls are complete. It is made to adhere to the walls by some mechanical expedient which seems quite effective. There is no doubt that entire solidity of lining would be an advantage, and if anything more durable than fire-clay can be had, the additional benefit may easily be imagined and readily appreciated.

Double puddling furnaces are an advantage where the puddlers can be induced to work together. If one waits for the other the disadvantages make the saving on the whole a doubtful matter, double the quantity of pig is charged, and where the running-in process is adopted, one half the coal is saved (fully or more) when compared with the single furnaces working cold iron. But the loss of iron where the workmen do not bring their heats up at the same time, more than causes loss equal to the saving of coal.

Truran makes a distinction between the boiling furnace and the puddling furnace, principally confined to the lowering of the flue-bridge and raising the bottom to within eight inches of the door. In boiling the crude iron it is usual to withdraw the balls before charging afresh, but in puddling, the pigs are introduced so that the decreased heat is due to the absorption of heat by the pigs, introduced back by the flue for the next heat.

For the protection of the sides of the furnace, which, because the cinder did not cover them, have been rapidly burned away by the iron, the Welsh use fire-clay, but calcined forge cinders, calcined so far as to make a refractory silicate of iron, are very successfully used. Cinders containing much iron, and little silica and alumina, are not so good as leaner cinders. Limestone seems to be preferred in some places.

Protecting Puddling Furnaces with Water.—Metal troughs, protected with thin layers of fire-brick, have been used, and air or water passed through constantly.

But the water being obstructed has caused explosions, and beside, it has been found that the absorption of heat has rendered it doubtful whether any advantage has accrued, and in some cases it was plain that the plan was air injury. The theory of the furnace, in its reverberatory arch and in even the glaze of the brick, is to obtain the highest amount of heat and expend all upon the metal, and by ascertaining the temperature of the water on entrance and of that water on its exit, and the quantity heated per day, the whole loss can be easily calculated. With a wall eight or nine inches thick of fire-clay brick little heat is conducted off; and this brick lasts generally from three to four months, according to the intensity of heat and the nature and quality of brick.

The horizontal area of chimney flue, at the juncture with the furnace, is determined from the nature of the coal used; a very bituminous coal requiring a larger area than one less. This area, called by furnace makers "the take up" with very bituminous coal and with a grate measuring two feet eight by three feet nine, is eighteen inches square, or thirty-two inches of flue area for each superficial foot of grate. When the coal is semi-anthracite the take up is seventeen inches by ten inches for the grates; two feet four inches by three feet five, or twenty-one inches of flue-area, for one foot of grate. Uniformity in the quality of the iron requires, with good puddling, uniformity in the size of the take up, and the constant wear or corrosion of the take up causes the restoration of that part necessary, else the waste of iron becomes very great.

Dampers to the flue stacks have been built at the bottom of the flue stack, and so arranged as to fall into the side of the stack upon and across the draft, but the sudden cooling and expansion of that part of the stack above this flue, renders it of great disadvantage.

Cast Iron Bottoms.—In the early puddling furnaces the body or hearth was composed of cinders, or other material, only covered with sand. The yield was great, but the iron was silicious and inferior, but the use of heavy hammers caused the exudation of much of the

silicate, but with consequent loss of iron, the ton of puddle bars calling for thirty cwts. of refined metal, and often as high as thirty-six cwts. But the *plate of cast iron* for the bottom introduced, and which caused much surprise at the hardihood of such a suggestion, in later times, has been attended with great results, second only "in importance to the invention of puddling itself." The same results, in quantity of puddled iron, are reached with only expenditure of twenty-one cwts. of the ton of refined metal.

An objection to the *utilization of waste heat* was made by Truran, on the ground that the draught was checked, iron wasted, and coal consumed, and that by experiments at Dowlais; but later experiments have shown, in this particular, the practical mistake on the part of a practical man, and now utilization is adopted where once it was thought impossible.

The Mechanical Processes in Puddling.

In the most carefully conducted process the bottom, or hearth, is covered with broken cinders and iron scales (hammer slag). When, after ten to twelve hours (in new), and five to six (in old) furnaces, from the time of lighting the fire, the white heat point is reached with a good fire in the grate, the slag and scales melt, and flow over cracks and protect the hearth; then checking the draught, about thirty to forty pounds (in single furnaces) of cinders are charged, and three and three-fourth to four and a half cwt. (in thirty or forty pound pieces) of pig iron to the "charge" are put in. These are evenly distributed, and all access of air prevented, all holes are stopped, not excepting that in the door, by pieces of coke and cinder—the draught is cleared both in the grate and in the stack—more coal put on and highest heat produced.

In about twenty minutes, sixty to eighty pounds "mill" cinder from the bars called "mill bars," are thrown in (these cinders drop from the rolls), the cinder from the puddled rolls, or that falling from rolled

puddled iron, contains more silica, and being less fluid is supposed to give rise to poorer iron.

The pigs when red-hot are changed and subjected to the heat in various positions. The edges of the pigs begin to melt, they are lifted to prevent adhering, and presently (in about five or six minutes) melt more fully.

Fuel must be added every few minutes, draft of grate kept open, and pigs lifted and changed.

In about thirty minutes all are melted, and the rabble introduced, and constant raking from below and around must begin. Boiling commences—bubbling, and spitting, and frothing through, and in, the half fluid supernatant cinder. In five or six minutes the damper is lowered—the effect is seen in the less liquid condition of the mass—the iron is more pasty—and if it adheres to the rabble, must be struck off by hitting the hand end with a hammer, which disengages the iron from the furnace end. The iron now must be raked up so that, if possible, every part may be exposed to the decarbonizing influence of the passing draft—while a kind of fermentation, called “coming to nature,” is in process—and the more constant and consecutive the effort at working the mass, the better, in order that the iron may be kept from being oxidized while the impurities alone take up the oxygen. The scale and slag, or cinder, subside around the pasty iron and toward the bottom, apparently as liquid as water, and then the iron is ready for balling.

Perhaps nothing can give a clearer idea of the process, than the following minute description by Dr. Percy, of a working by a good puddler, remembering that the time must be modified by fuel and iron.

“I know scarcely any metallurgical operation more interesting to watch than puddling. I will now present a detailed description of it, as I saw it practised by one of the best puddlers in South Staffordshire, at the Bromford Iron Works, in 1859. Dr. Beddoes presented to the Royal Society, March 24, 1791, a description, of the process of puddling *gray* pig iron from his own observations. The charge was two and a half cwts. The furnace had two chimneys, one at the end as at present, and another over the fireplace. Both had dampers. When the damper of one was up, that of the other was down, so that the

flame might be made to pass over the bed, or direct into the chimney over the fireplace. Dr. Beddoes' account is very circumstantial and correct. He especially dwells on the 'fermentation' and the evolution of blue jets of flame over the surface. He has recorded one observation of interest, namely, that the metal at one stage became decidedly hotter after the flame had been turned off from the bed. He did not rightly interpret the fact, which is due to the heat developed by the combustion of the iron.

The side plates are lined either with 'puddling mine' (roasted red mine, a black band from North Staffordshire, see table of iron ores), or 'bull-dog' (roasted tap-cinder), or with both, and the bottom is covered, as previously stated, with a layer of oxide of iron. The bull-dog is crushed between rolls; the large pieces are first put in and then covered with crushed mine or bull-dog; and the whole is plastered over with red hematite (of the unctuous or soft variety) made into a paste with water, and afterwards rammed well in. The brickwork at the sides is, as shown in the engravings, built to overhang the bed, whereby a space is left underneath for ramming in the mixture above mentioned. In every turn or shift of twelve hours, about one cwt. of scrap wrought iron is introduced into the furnace and worked into a ball, in order to supply a coating of oxide of iron over the bottom.

July 21, 1859. The cinder having been tapped off, and the furnace being supposed to be ready for the next heat. The charge consisted of a mixture of one cwt. of refined iron and three cwts. of forge pig iron (long weight as usual), and about one cwt. of hammer-slag and iron scale.

1h. 5m. Hammer-slag was put in, and spread over the bed and round the sides. This charging was effected in about 3m., the damper being up all the while. The door was let down and wedged, as before described, and the working hole, or, as it is termed, the stopper hole, at the bottom of it was closed up with a bit of bar iron. The tap hole was stopped up with sand. Coal was introduced, and the fire "fettled." Smoke and flame issued from the top of the stack. Nothing more was done until 2h. 9m.

2h. 9m. The puddler's assistant or 'underhand' put in coal. The puddler lifted or moved about the pig iron through the stopper-hole with his paddle, which required about 2m.

2h. 15m. The underhand repeated the last operation of lifting or moving about the pig iron, detaching any pieces which stuck to the bottom. This is done in order to allow the flame to play on all parts of the iron, the bottom of the furnace being the coldest part. Before withdrawing the paddle, it was struck

with a hammer in order to knock off any iron adhering to it. Stirring and rabbling were constantly practised by the underhand.

2h. 16m. The whole of the pig iron was not yet quite melted. The molten portion 'frizzled,' as though in incipient ebullition. When near its melting point the pig iron may be easily broken up.

2h. 25m. The fire was replenished. The puddler rabbled constantly. All the pig iron was completely melted. Up to this time the damper had remained up, but it was let down after the pig iron had melted. The letting down of the damper will depend upon the temperature of the furnace. If the furnace is 'very cold,' the metal will 'come up' without. [The meaning of this term will be understood from what follows.] The underhand stirred incessantly.

2h. 36m. The fire was made up by the puddler, the stirring by the underhand having continued without interruption. The damper was raised.

2h. 40m. The puddler, naked to his waist, took the rabbling in hand. The molten metal presented the appearance of full ebullition, technically termed 'boiling,' and was swelling up and rising rapidly, jets of blue flame escaping everywhere from its surface, and the metal being spirted up with considerable force, thus showing that the formation of carbonic oxide must take place deep below the surface, owing to the oxidation of the carbon in the metal by the oxygen of the hammer-slag or other oxidized products of iron. The paddle received a swinging movement from side to side, as well as backwards and forwards.

2h. 43m. The molten metal was almost white-hot, and had risen nearly to the stopped hole.

2h. 45m. The metal had not risen higher, but had become whiter and hotter by stirring. The damper had been up about 10m. Coal was thrown in through the staff hole.

2h. 53m. The underhand took the paddle; the puddler having done the work since the time of the last observation. Much of the iron had 'come to nature,' producing pasty masses in the liquid cinder. It is beautiful to witness this separation of the malleable iron.

2h. 56m. The puddler worked again.

2h. 58m. The underhand now worked.

2h. 59m. The puddler resumed work, the damper still continuing up.

3h. 5m. The first ball was taken out, the damper was partially let down, and the stopper hole closed. The reason of this is obvious; for as soon as the iron has 'come to nature,' oxidation

must cause unnecessary waste. The body of the furnace should be full of smoky or reducing flame to prevent this effect.

3h. 6m. The second ball was taken out.

3h. 9m. The third ball was taken out.

3h. 11m. The fourth ball was taken out by the underhand, the preceding ones having been withdrawn by the puddler.

3h. 13m. The fifth ball was taken out.

3h. 14m. The sixth and last ball was taken out, immediately after which the cinder was tapped off. A ball weighs about eighty pounds.

The puddler was one of the most, if not the most, skilful in the forge. He was about thirty-eight years of age, and about five feet ten inches in stature. He complained that the work was much harder now-a-days than formerly, when not more than two cwts. or three cwts. of pig iron were puddled at one heat; but Mr. Arkinstall assures me that this is entirely untrue, and that during the last thirty years the charge has never been less than four cwts. He, however, admits that the work is harder now than formerly in consequence of the pig iron being more impure."

Gray varieties of iron require from twenty to twenty-five minutes more work in "coming to nature" (as the workman styles that condition which admits of the iron being balled up).

The difficulties in regard to time and labor in the mechanical process are found as follows:—

1. In iron containing large per cent. of carbon—as, *e. g.*, those smelted from carbonaceous ores—they fuse at low temperatures, and contain much carbon, hence are oxidized easily, the impurities are not extracted, and the iron is burned, for they cannot be stirred up sufficiently and for a time long enough for the object intended.

2. Absence of a good cinder for protecting the iron (and absorbing, or neutralizing silica).

3. Presence of sulphur.

4. Presence of several metals, including copper, lead, zinc. If these exist in considerable quantities, the balling up is prevented, and a granular and non-adherent condition exists, despite all efforts of the puddler.

5. Inferior coals, especially slaty anthracites, when used with a simple air-stack, and even when a blower is used. The above difficulties cause waste, loss of time,

and inferior quality. The *produce is improved*, during the process, by conversion, by addition of a mixture of ground magnetic oxide, or a rich hematite, caustic lime, and minimum dose of manganese, five or six per cent. by weight of the charge. The oxygen of these ingredients probably combines with the carbon, thus purifying the iron thus far; and it may combine with other bases forming oxides, perhaps with sulphur as well as carbon.

Puddling from blast furnace iron run into the puddling furnace has been tried nearly a half century ago, (Truran p. 8, ed. 1850), but the crude iron was run into the puddling furnace from the refining furnace. The difficulty was found in separating the cinder from the metal, and if they escaped together into the puddling furnace the quality of iron was injured. Puddling crude iron direct from the blast furnace is practised with the advantages that one-third coal is saved, thorough melting is insured and more uniform iron obtained. The disadvantages, are too close proximity of blast and puddling furnaces, causing inconvenience in moving about and uncomfortable heat.

Puddling with Steam.—This method was tried at the Dowlais Works, originally, some years anterior to 1850. It was considered a great improvement in time, quality, quantity and economy generally, the steam was conducted down, vertically, through telescopic tuyeres, which could be depressed and elevated under the direction of the puddler, and which passed through the roof of the furnace. After the heat was removed the steam was directed upon the fluid cinder which when it was cooled down to the pasty condition, was raked up against the back and sides of the furnace, and, taking the place of clay and limestone formerly used, was considered a great help as repairing of the openings of the furnace thus executed, prevented the injury done to the quality of the iron resulting from additional earthy impurities resulting from fresh addition of clay and limestone.

The *disadvantages* were, that *in the large way* the expense attending the generation of steam exceeded the gain, and the experiments seemed to have been made,

and the test approved, before any patent was taken out. Otherwise, than as aforesaid, the advantages seemed in all respects great, but Truran supposes that the workmen were to be credited with any superiority which was actually discovered, and remarks that workmen will make in the "bring out" a nearly equal quantity with the charge, "and obtain from a furnace twenty or thirty tons weekly, where others are working with a loss of one and a half cwt. to the ton, and unable to make twenty tons of inferior bars in the same time." Hence in published reports allowance must be considered and made for the *skill* of workmen.

A steaming apparatus combined with a blast and rapid decarbonization of the metal by *heated blast* was attempted (1855), but the waste of the iron caused its abandonment.

Methods of Refining.

The following is the refining process adopted in making the finer irons, in Wales and some parts of England, not, however, in the inferior irons (Truran). The furnace is generally about four feet square and the hearth about eighteen inches deep, provided with two tuyeres to the side, with nozzles varying in opening from one and a half to one and five-eighths inches, at the smaller and three and a half to four at the larger end. *Flattening* the nozzle at the hearth end is thought to be preferable.

The metal, either cold, or, run in molten from the blast furnace, is commingled with charcoal, coke or raw coal, remelted by the blasts turned on and afterward directed (best) at an angle to the surface of the molten metal, equal to 38° and to each other (on each side) equal to 105° and thus refined, by deoxidation (by the heated contact coal absorbing oxygen) or subsidization of some impure matter.

It is then drawn off and cast in moulds into pigs generally of flat form and rectangular, called plates. The moulds are of cast iron suspended in water troughs.

Iron smelted with caustic lime in place of limestone

is not so fluid either in the furnace, or refinery, and in the latter requires, therefore, a longer blowing before the tenacity is such that the specifically lighter matter may rise, hence more difficult to work. Yet this iron, thus fluxed with caustic lime, is preferable in the rolling mill, and the quality in the end is superior. The addition of either caustic lime or limestone, broken into small pieces, to the iron during the process of refining is of advantage to the quality of the metal. Proportions from twenty to thirty pounds per ton. The coke may be impregnated with caustic lime in proportion of twelve to eighteen pounds per ton. Thus treated, the improvement is "very marked," but an excess over the above seems to produce red-shortness, and it is said that the above treatment is applicable to the lean carbonates of the coal formations.

Even six pounds potash to the ton seemed to injure the quality of the iron increasing the tendency (whether or not existing originally) to red, or cold-shortness.

The effect of the refining process upon crude iron "run in" molten from the blast; or after one and three-quarters of a hour melting, may be seen by the following comparative analyses after the two conditions.

	Crude iron.	Refined plate metal.
Iron . . .	95.26	98.33
Carbon . . .	2.63	.87
Silicon . . .	1.38	.53
Aluminum . . .	.73	.26
Phosphorus . . .	trace.	trace.
Sulphur . . .	trace.	trace.
	<hr/> 100.00	<hr/> 99.99

Cinder produced in the operation of refining this iron.

Protoxide for iron	70.3
Silica	21.5
Alumina	7.8
	<hr/> 99.6

All the crude irons smelted with the hot blast are refined with greater loss than occurs in similar refining of

crude iron smelted with cold blast. The difference per ton is equal to thirty-six pounds average.

Crude iron is refined with greater waste in cases when the cinder is in excess, for while the proper amount protects the surface of the molten iron, the excess causes waste in the refinery. If the coke is of a weak and friable kind and not dense, the consumption is not only greater, but it is followed by a loss of iron (crude).

The consumption of blast, according to Truran, in refining "forge" iron is about 94,000 cubic feet per ton of metal produced, in weight 7076 lbs. [7110 at 13.22 cubic feet to a pound] and of pure oxygen 1684 pounds [more accurately 1627 lbs. as atmosphere = 23O. + 77 N in 100 parts] distributed thus:—

Combustion of 430 lbs. carbon in the coke .	1146.4
Decarbonization of the crude iron . . .	122.4
Formation of the Fe O of the cinder . . .	51.8
Formation of silica from silicon . . .	24.8
Formation of alumina from aluminum . . .	11.9
Wasted during process (17 per cent.) . . .	290.7

The above is asserted of "running-in" fires in contradistinction to "melting down" fires. In the latter the consumption of blast is equal to 136,000 cubic feet, with "forge" qualities and with gray iron 153,000 cubic feet. The density of the blast being about equal to that of the blast furnace. Refineries are worked with about one and a half pounds to the square inch (minimum) to two and two and a half, the more common. The lighter cokes require less blast. The reason of difference being that, in the refinery, the blast is directed upon the surface of the molten iron, and hence a high pressure would lead to combustion of iron, whereas in the blast furnace the air does not impinge upon the iron.

Refining by Mixtures.—We have frequently been shown, *patented powders* for improving iron, some of which are undoubtedly beneficial, others are not. The following ingredients are most commonly used: Salt, prussiate potash, saltpetre, manganese (black oxide), litharge, permanganate of potash, nitrate of soda, fluor spar, cryolite,

pulverized Jersey red zinc ore, and caustic lime; any of these may be of service under certain conditions of the iron to be puddled, but the quantities, mixing, the economy as well as the choice are all dependent upon the judgment of the manager and the nature of the iron. All sulphates of iron, of copper, of baryta, &c., create red-shortness in iron, but may be used to correct contrary qualities. Fluor spar and cryolite have been found to produce excellent results in eliminating both sulphur and phosphorus.

Incorporation of other iron material with the iron to be puddled may improve it in some one or two properties, but sometimes at the sacrifice of others equally desirable. Certain pig irons puddled with pigs of other qualities, judiciously selected, may greatly improved the strength, hardness, or quality in other respects. This mixing is practised at one or two puddling furnaces within our own personal knowledge with singular success.

CHAPTER III.

PRACTICAL REMARKS ON CHARCOAL FORGES, PUDDLING AND REFINING.

[*a.* It is undeniable that charcoal forge iron is, in many respects, superior to puddled iron. For all the purposes for which wrought iron is applied, it is more malleable, compact, and durable. The charcoal forge will be needed so long as the puddling process does not furnish a quality of iron equal to it.

It is questionable whether the charcoal forges of the West, and even in the heart of the anthracite and bituminous basin, do not yield larger profits than the puddling forges and rolling mills; at least, an investment in charcoal establishments may be considered quite as safe as in those of stonecoal, at the present time.

The location of charcoal forges should depend upon

the supply of ore and wood. Inferior ore, and the metal smelted from it, are less useful to the charcoal fire than to the puddling furnace. The success of the former depends upon the quality of the metal with which it is supplied. It is thus evident that the best is always the cheapest metal. This rule is not applicable to puddling establishments. In addition to this, the charcoal forge requires good coal. But rich ore, or excellent metal, may counterbalance expensive coal; while poor metal and expensive coal will yield only unprofitable results. Where the metal is good, a ton of iron requires only 150, and sometimes only 120 bushels of charcoal; and seven tons can be produced in a week, with but one fire. But where it is poor, a ton will require from 200 to 300 bushels; which only two or three tons of iron per week will be produced. We refer to blooms, not to drawn iron. Consequently, should the iron resulting from the smelting of good or bad metal be equally valuable, which is not a fact, the expenses of manipulation are so decidedly in favor of the former, that the question which to choose will never arise.

b. The magnetic ores of the States of New York, Vermont, New Jersey, and Missouri, afford an excellent article for the charcoal forge. The spathic carbonate, the specular ore, and the red aluminous ores, also constitute an excellent article for the charcoal forge; but these are not so generally distributed as the magnetic ore: The rich hematites of Tennessee and Alabama are adapted to the Catalan forge. The same reasons which may be assigned against the working of poor ores in this forge, apply against their use in the charcoal blast furnace. Inferior metal is, at present, employed in the coal regions for the manufacture of charcoal blooms; but we predict that these efforts will, in a short time, be abandoned, because poor charcoal iron cannot successfully compete against puddled iron. Metals which contain phosphorus, or sulphur, are not adapted to the charcoal forge, because of the inferior iron they produce and because of the amount of time consumed in converting them into bar iron. All metals derived from

impure bog ores, sulphurets, silicious ore, and ores containing phosphorus; all the gray metals smelted from poor ores, particularly those of silicious origin; and all white metal resulting from small burden, inferior ore, and bad management in the blast furnace, are improper for the charcoal forge.

c. The necessity of good metal in the forge is illustrated by the following fact: An instance is recorded in which a ton of blooms, from white metal of excellent quality, was produced, with the consumption of only ninety bushels of coal; while, on the other hand, when gray pig iron was used, 400 bushels of coal were consumed in producing the same amount.

d. The site of a forge is generally selected in relation to facilities for obtaining water power; but it is probable that steam may prove to be the preferable power, because the waste heat of the forge fire is sufficient to generate it. It is also probable that the first outlay in erecting the works is, at least in a majority of instances, in favor of the steam-engine.

e. The application of hot blast to the charcoal forge is of questionable advantage. It will save fifteen or twenty per cent. of coal; but labor is increased, and the iron depreciated.

General Remarks on Puddling.

This method of converting cast iron into malleable iron is designed to supersede every other method by which that result is effected. But, thus far, the quality of puddled iron has been such that we have been unable entirely to dispense with the charcoal forge. Still, this quality would be much improved if better metal was generally employed. The nature of the puddling process is such, as we have elsewhere stated, that we are enabled by it to employ *inferior metals* to a great degree. Thus, blast furnaces have been erected at places where charcoal forges would not have flourished. Inferior pig iron answers tolerably well for the puddling furnace. Metal perfectly useless in the charcoal fire will, in this

furnace, produce a very good article. In fact, every kind of pig iron, however bad in quality, may, by the puddling process, be advantageously worked.

a. In the Western States, where charcoal pig is puddled and boiled in single furnaces, iron of very good quality is made. A great deal of inferior iron is also produced, which according to the metal used, should be of better quality. The puddling furnaces of the West work well; but it is doubtful whether due amount of labor is spent in working the iron. The puddlers generally finish a heat in less than an hour and a half, including shingling; and the boilers in less than two hours. At other places, this is considered an insufficient time to do full justice to the work. At some well-regulated Eastern establishments, twelve hours are consumed for five boiling heats, and the same time for six puddling heats. This may be considered fair time for industrious and judicious manipulation. Where the metal is of superior quality, less attention is required. But throughout the United States the tendency of most blast furnaces is to produce gray metal; consequently, the manufacture of good bar iron requires great industry, however good may be the ore from which it is smelted.

b. As previously remarked, at Pittsburg and the Western Works, boiling was formerly carried on in about one-half of the puddling furnaces. Those used exclusively for puddling were regarded as necessary evils, and were employed merely to make cinder for the boiling furnaces. Excellent cinder is produced from metal of good quality, carefully puddled; but, on account of the refining of the crude iron before it is taken to the furnace, this operation is expensive. All the advantages which the process includes are realized at the Western establishments. But, unless other methods are adopted by the Western manufacturers in working pig metal, competition will gradually exhaust all the profits of this business. This, let us observe, is a more important matter than it seems to be, for, if puddling is replaced altogether by boiling, the question meets us, whence is the neces-

sary supply of cinder to be obtained? Charcoal forge cinder, at present frequently applied, cannot be obtained in sufficient quantity. Artificial fluxes, then, are the only resource of the Western manufacturers. Good iron ore will serve as an excellent flux; but this cannot be found either in the Western or in the Eastern coal regions. In the State of New York, the magnetic ore from Lake Champlain is employed; and the furnaces of this State not only produce excellent iron, but furnish a more abundant yield than any we have ever seen. At Saugerties, on the Hudson River, 2000 pounds of rough bars have been made from an amount of pig iron varying from 2075 to 2100 pounds. Loss only from three to five per cent. Amount of anthracite coal consumed from 1600 to 1700 pounds. Furnaces double, with iron air boshes; charge 750 pounds, and five heats in twelve hours. The magnetic ores of Missouri, and the red oxides of Arkansas afford a good material for the Western mills; but ores of the coal formation are not sufficiently pure. The amount of good ore required per ton of inferior pig iron is sometimes from 400 to 500 pounds; but for excellent metal, rarely beyond 200 pounds.

c. We have stated that most puddling furnaces are provided with iron boshes. But in those which work anthracite iron, soapstone is employed for keeping the boshes in order. It is evident, that if iron boshes were proved in all cases to be advantageous, they would be adopted. But in the present case, they are of doubtful utility, as we shall explain.

The necessity of enlarging the hearth, so that a smaller surface of the boshes, in proportion to a given amount of metal would become cool, originated the double furnace. It was found that the cooling influence of the iron lining in small or single furnaces was so great that in

to resist the action of strong alkalies ; but the necessity of cooling the boshes is so strong a counteracting element, that the beautiful theory of improving iron by means of artificial cinder is but of limited application. In this respect, double furnaces present greater advantages than single furnaces ; and boshes cooled by air are superior to those cooled by water.

In the improvement of bad pig iron, by puddling, our primary object should be to melt it perfectly, and then to remove its impurities by means of cinder. If, therefore, a hearth is so cold as to prevent the melting of the metal, the most essential condition of improvement is not realized. If the iron contains impurities firmly and intimately combined—as that from coke, anthracite, or even from charcoal furnaces, smelted with small burden—a perfect remelting is necessary. Such iron requires a strong heat ; and this heat cannot be produced in a furnace with cooled boshes. Hence the failure of experiments made to improve such iron. Anthracite iron contains a large amount of silex, in addition to carbon ; and a furnace with water boshes is unable to produce a heat sufficient to melt it perfectly. Fibrous bar iron is preferable, as an article of commerce, to that which is cold-short ; and to prevent it from becoming cold-short, the intimate connection between the impurities and the iron must be destroyed. Therefore, a furnace with soapstone, or what is still better, good fire-brick, will produce a better iron for the market than a furnace with cold boshes. A uniform temperature of the lining and walls is required to produce a thorough solution of the pig iron. The presence of silex in large amount, as in a lining of soapstone or fire-brick, affords, by retarding the work, every facility for producing this result. This latter circumstance should be viewed rather as the least of several evils than as a positive advantage.

From these considerations, it follows that pig iron from small burden, or made by a high temperature in the blast furnace, cannot be perfectly improved in a furnace with water boshes ; and that the application of these boshes should be limited to such iron as will thoroughly

melt at a medium heat. Consequently, white metal containing a large amount of carbon, anthracite, coke, and charcoal iron from small burden and hot blast, as well as all refined metal, are excluded. Pig iron from heavy burden, and from ores containing phosphorus ; gray charcoal pig; and, in fact, all metal which readily melts, and keeps liquid for a considerable time, are, of all others, the most serviceable in the end.

d. Our own experience, which is somewhat extensive in this branch of the business, proves that white metal from the richest ores is unfit to be worked at all in a furnace with a cooled hearth ; and produces far better iron in brick linings. Pig iron from small burden and coke, we never succeeded in improving. With white iron from charcoal furnaces and small burden we were equally unsuccessful. The most favorable pig iron is that which is made by a small quantity of coal and by low temperature in the blast furnace. The lower the temperature, the better the iron. Pig iron smelted from phosphates, is easily converted into the best kind of bar iron, if the temperature of the furnace has been low, or the burden heavy ; but if smelted from the same ore, and by a high heat, whether charcoal, anthracite, or coke, it is improved with difficulty ; sometimes total failure results. The same rule is applicable to pig iron smelted from silicious and sulphurous ore. In fact, it may be laid down, as a general rule, that the smaller the amount of coal consumed, or the lower the temperature of the hearth in the blast furnace, the better will be the quality of the metal ; that is, the more fit it will become for improvement in the puddling furnace. We thus see the advantage of heavy burden in the blast furnace, for it not only reduces the first cost of the metal, but makes a far superior article for subsequent operations. We may safely say, that the worst cold-short or sulphurous metal, smelted by a low heat, is quite as good as the best metal from the best ore smelted by a high temperature. We will give a practical illustration.

Some years ago we were engaged in improving cold-short iron ; that is, pig iron smelted from bog ore, which,

before that time, possessed no value whatever. Our manipulations were conducted in a double furnace, with water boshes. The puddling was carried on by means of artificial fluxes. We succeeded, without difficulty, in producing a beautiful bar iron, in quality equal to the best in the market. With the object of testing its virtues, a portion of it was sent to a distant mill, and converted into wire. So successful was the result, that the puddled iron was preferred to the best charcoal iron. At the wire mills, where an extensive business was done, a large quantity of charcoal iron was needed. As this could not be obtained in consequence of its expensiveness, puddling works were erected for the purpose of furnishing iron for the inferior qualities of wire. At this establishment, steel metal of the most superior kind was wrought, which of course, puddled in single furnaces, with good fire-brick lining, made an excellent bar iron. After using the iron of our cold-short metal, the owners of the rolling mill entered into an engagement with us by which we bound ourselves to furnish as good an article from their superior plate metal as we had made from worthless phosphorous pig. A few heats made in one of their own puddling furnaces indicated that improvement was possible; but, owing to certain peculiarities of the new process, puddling could not be performed in a brick lining. We therefore concluded to erect a double furnace at once, and apply iron boshes. Until that time, our practice had been confined principally to the worst kind of pig iron, and accompanied with more or less success, according to the nature of the metal with which we had to deal. We entered upon the undertaking with great confidence. The idea of failure never entered our mind. This confidence appeared to be justified on account of the insignificance of the improvement required, compared to what we had already arrived at. The metal was the best which the Continent of Europe afforded; but, after all our exertions, the ultimate result was a total failure. As this is one of the most remarkable as well as interesting cases which ever happened, we shall relate it somewhat in detail, and thus serve a useful pur-

pose. The metal used was smelted from sparry carbonates; it was almost crude steel, that is, white metal containing carbon in large amount. Being thoroughly acquainted with the most important part of the operation, we took great care to have a furnace of good heating capacity. The metal melted in a short time, and at a low temperature; but the least stirring with the tools made it crystallize, and worked it into nature; and sufficient time was not left to enable us to mix it properly with the cinder. The result was a dry, hard iron which broke under the hammer. No effort was left untried to overcome this apparently trifling difficulty; and when we at last succeeded, a very singular circumstance put a stop to the experiments. The breaking of the balls under the hammer is in all cases, the result of too slow work. The workmen did their best; but the iron worked too fast. This is generally the case with white iron containing a great deal of carbon. The application of fluxes retarded the process. At last the metal worked well, and became soft and tenacious iron. But, when piled and reheated, a number of the bars broke in the merchant rollers; and the iron, commonly of a silvery white appearance, exhibited in its fibres a dark color. On a second reheating, both in a blacksmith's fire and the reheating furnace, it broke up into small fragments. In fact, it was iron no longer, but black magnetic oxide. Rolled down to half inch rods, it broke into fragments on the first heat. Bars one and two inches square exhibited on their surface a high degree of oxidation, and appeared, internally, of a fibrous, dull yellowish color. On the application of the slightest heat, this color changed to black.

The above experiment is a highly interesting one. It shows clearly the legitimate scope of improvements, and the direction in which experiments should tend. The metal employed was, as we have stated, of the best quality. It furnished excellent steel with the greatest facility. In the charcoal forge, it furnished the strongest kind of bar iron—consuming per ton of iron only from 110 to 130 bushels of charcoal. In the single puddling

furnace, with brick lining, it produced a firm, tenacious iron, but of too coarse fibre, and containing too much cinder for the manufacture of wire; while in the puddling furnace with iron boshes, it did not work at all, and ultimately returned to its primitive condition—that is, became oxidized to ore.

The establishment where our first operations were conducted was a very inferior one. The metal used, whether in castings, charcoal forge or puddled iron, was almost worthless; at least, it commanded a very low price in the market. The pig iron, smelted from phosphoric ores, was cold-short in the highest degree, perfectly useless in the charcoal forge, and a poor article in the common puddling furnace. Yet this worthless metal was converted with the utmost facility, into bar iron superior to any kind in a market where the first quality of charcoal iron was alone saleable. The amount of charcoal consumed in the blast furnace was only from 80 to 100 bushels, notwithstanding the ore yielded but twenty per cent.; while from 180 to 200 bushels were required in producing a ton of the steel metal on which we experimented.

The experiments we have described are extreme cases; but they exhibit clearly the method by which we can arrive at the most favorable results. We always failed when we attempted to improve white iron from an overheated blast furnace, even though the ore and coal were of the best kind. We failed with the best white metal of the Continent of Europe; with the steel metal of Siegen and Styria; with white Scotch pig; with the white coke iron of the fossiliferous ore of France; and with the coke iron of the Mount Savage Iron Works, Maryland. But we always succeeded in improving both the quality and yield of pig iron from a tolerably well-conducted blast furnace operation.

e. Experience thus shows what is required both for the charcoal forge and the puddling furnace. We will recapitulate the conclusions arrived at. Gray pig iron of a fusible nature is ill adapted for the former; but is the best of all kinds for the latter. White metal containing carbon in small quantity, or smelted by heavy

burden is good in either case ; but white metal from poor ores and light burden is in all cases inapplicable. White metal from rich ore and light burden is superior to all in the charcoal forge, but in the boiling furnace it is almost useless. We may hence conclude that cold iron boshes are of great advantage where pig iron from a well-regulated blast furnace operation is wrought ; but that, where white pig iron from small burden and a high temperature—as in coke and anthracite furnaces, in which an excess of limestone is used—is to be converted into bar iron, they are disadvantageous. In the latter case, a fire-brick or soapstone lining is preferable.

f. Thus far we have considered simply the best means of making wrought iron. But if we wish to produce wrought iron for specific purposes, it is not a matter of indifference what kind of apparatus we employ. Merchant iron should be malleable, fibrous, and of good welding properties. This, as well as very cohesive wire iron, is manufactured in great perfection in the charcoal forge, and in the double puddling furnace with iron boshes. But railroad iron should not be made in either of these furnaces. Easily welded iron is made by allowing a small portion of carbon to remain in the metal, and by expelling, as far as possible, all foreign matter from it. But this, by destroying the fibre, will make iron of large dimensions cold-short. By reheating and rolling small rods, the carbon will evaporate. If, therefore, we want fibrous railroad or any heavy bar iron, we must employ a metal free from carbon, iron from which the carbon is easily expelled, as that from the run-out fires. This is to be puddled in a very warm furnace. A cooled puddling hearth produces a good welding iron ; but the long exposure of large piles of this iron, such as are necessary for railroad, heavy bar iron, and boiler plate, to a welding heat, occasions great waste. In all such cases a brick lining is preferable to cold boshes. Wire iron should be of the best quality ; but the puddling process by which it is produced would be inapplicable for railroad iron, for the latter would thus become cold-short. Iron designed for small rods, hoops, gas-pipes, and wire, ought to ex-

hibit a crystalline fracture, a steel-like grain, which is produced by carbon. But of all other foreign matter it should be free. Silex and phosphorus will not evaporate like carbon, on repeated exposure to heat ; and iron which contains either in a non-vitrified state, will be cold-short under all circumstances, and will be useless for wire, or for any purpose for which strength is required.

Wire iron, or merchant iron, should be manufactured from gray pig, which, unless improved by artificial cinder, must be of the best quality. By boiling with artificial cinder, any kind of gray pig may be converted into good iron in the puddling furnace with iron boshes. In a cooled hearth, all foreign admixtures can be expelled from the metal, and yet enough carbon retained to preserve its welding properties. This advantage is accompanied with a disadvantage ; for the carbon, as we have before stated, makes the iron, when in large masses, cold-short, and occasions waste in the reheating furnace. Piles of 700 or 800 pounds in weight, exposed to a strong heat in the reheating furnace, will melt at the surface, without becoming, in the interior, sufficiently hot for welding.

A specific kind of iron is required for nails, an important article in our iron works. Nails cut from charcoal iron are generally supposed to be of good quality ; still, this iron, whether from the charcoal forge or the puddling furnace, furnishes an abundance of inferior nails. With respect to nails, the intrinsic value of the metal—that is, its absolute strength, and welding properties, as in the case of wire iron—has no influence whatever upon the value of the manufactured article. All that is desired in a good nail is, that it shall cut smoothly, and bend to a given degree. Iron containing an amount of foreign matter that would make it useless for any other purpose, answers excellently. Such iron may be manufactured from any kind of pig metal without difficulty, provided the reheating and heating are carefully performed. Two different methods of manufacturing nail plates are now practised. In the Eastern States, plates from five to twelve inches in width, but of no specific

length, are drawn ; nails are obtained from cutting these lengthwise. In the Western States, it is customary to roll sheet iron from twenty to twenty-four inches in width, and six or seven feet in length ; and nails are obtained from strips cut crosswise. Which is the preferable method, it is not easy to decide ; but the immense quantity of nails manufactured will justify us in giving the subject a close examination.

To make a nail which cuts smoothly, and does not split, we require an iron of very close grain. For this purpose, cold-short answers better than fibrous, particularly coarse fibrous, iron. Iron is rendered cold-short by carbon, phosphorus, and silex ; the two latter cannot be removed by reheating the iron. But reheating will remove carbon ; and, therefore, when we take into consideration that iron which contains some carbon can be welded with greater facility, and by a lower heat, than that which is free from it, it is evident that a small amount of carbon should exist in the iron before it is placed in the reheating furnace. From this it follows that, if we reheat the iron, and reduce the size of the nail-plate, the iron in the rough bar ought to be cold-short ; it will be fibrous after it is reduced. So far as the principle of working it is concerned, this iron is analogous to wire iron. The latter is best manufactured in the charcoal forge, or in the puddling furnace with iron boshes. Consequently, nail iron should be boiled in this furnace, provided it is repeatedly exposed to a welding heat, and drawn out into small-sized plates. But if it is our design to make sheet iron, that is, by exposing the plates to the suffocating heat of a warming stove, the iron will not be freed from the carbon, and remain cold-short. We thus see that, in one case, small plates are advantageous, and in another case injurious. To make nail iron from white metal, it is necessary to work the latter either in the charcoal forge, or in a puddling furnace without cooled boshes. From this metal good iron can be made in the charcoal forge without the least difficulty ; but in the puddling furnace with a soapstone or fire-brick hearth, we obtain an iron of coarse fibre, excellent for

many purposes, but not adapted for the manufacture of nails. If, in such cases, we attempt to leave a portion of carbon in the iron, silex will remain along with it, should not the pig iron already have been free from it; of course, such iron and nails will be cold-short, no matter by what method the iron is treated after leaving the puddling furnace. Good metal, puddled in iron boshes, will produce fibrous iron; but the danger is that it will lose all its carbon, and that, by repeated heating, a fibrous, dirty, yellowish-colored, rotten iron, both cold-short and hot-short, will result. To prevent this, and retain the fibrous texture of the puddled bar, it is preferable to heat in stoves, and to roll sheet iron.

Nail iron of satisfactory quality can be easily made, if we are well acquainted with the process of puddling. To work cheaply, we must resort to boiling. We may hence conclude that, in puddling for nail iron, we require gray or mottled pig iron, no matter of what quality, provided it is smelted by heavy burden.

To secure the presence of carbon, while we remove impurities from the iron, it is absolutely necessary to boil in iron boshes; and fine fibrous iron cannot be made, unless the pig metal is fusible, and remains fusible sufficiently long for the workman to wash it properly in the cinder. All gray iron of heavy burden—whether smelted by charcoal, anthracite, or coke, or whether the ores contain phosphorus, sulphur, or any other injurious element—is adapted for this purpose.

We thus see that the quality of bar iron may differ according to the different purposes for which it is employed. The blacksmith needs an iron which can be easily welded, which is neither cold-short nor hot-short. Wire iron must be strong, and very cohesive; it is of no consequence whether it can be easily welded, or whether it is cold-short or hot-short. Nail iron may be hot-short, but its fibre must be fine. Railroad iron may be anything but cold-short. The properties of the first three are produced by boiling alone. The latter, if manufactured in a cold hearth, will be imperfect.

g. The elements of pig iron are seldom of such a

nature as to afford the exact quality of wrought iron we require, and it need scarcely be mentioned that, when smelted from different ores, it will contain admixtures according to the nature of the foreign matter contained in each ore. A silicious ore will impart silicon to the iron; a phosphate, phosphorus; and sulphurets, sulphur; but as, under the peculiarities of the blast furnace, silicon and carbon have the greatest affinity for iron, they are most constantly associated with pig metal. One kind of metal exerts more or less influence on another. The same principle which we have observed in relation to the blast furnace, is applicable to the puddling furnace; that is, metals of different quality, mixed together, work better in the puddling furnace than metal smelted from the same kind of ore. A metal from calcareous ore works far better, when mixed with a silicious metal, than when mixed with iron derived from limestone ore; and if to the first two we add a metal smelted from clay ore, the result is still better. This peculiarity depends less upon the tendency of the foreign matter to form a fusible cinder, than upon the fusibility imparted indirectly to the metal by the foreign matter, and occasioned by their mutual affinity. Carbon occasions fusibility; and silicious and clay ores are more inclined than lime to give rise to a carburet of iron. An excess of lime not only excludes carbon, but it absorbs sulphur and phosphorus. Therefore, the least fusible iron is that smelted by an excess of lime. It frequently happens that a given iron is too fusible; that it works slowly, and yields badly. If to this we add a metal of a somewhat refractory character, which also works badly by itself, we shall find that a very advantageous mixture results. In this way, we are enabled to work the most unfavorable metals advantageously. For these reasons, it is advisable to work metals from different localities. In our attempts to work, in a puddling furnace with iron boshes, coke or anthracite iron, or even some kinds of charcoal iron, we frequently meet with an unexpected disappointment; and this disappointment results from the imperfect fusibility of the pig iron

in the hearth of the furnace. In such cases, artificial cinders are useless, for the best cinder cannot reach the impurities. These are inclosed in the particles of iron, and nothing but a perfect solution of the metal will remove them. This solution may be most easily effected by mixing with the refractory iron an iron that is very fusible. Admixtures in themselves injurious cease to be so if the metal can be perfectly dissolved and kept liquid until the cinder has had sufficient time to act upon it. In proof of this, it may be remarked that phosphorus or sulphur may be added as a flux to the half liquid iron; and, if the cinder of the furnace is of the proper kind, the metal manufactured will be neither hot-short nor cold-short. The application of sulphur or phosphorus as a flux is difficult and expensive; we should, therefore, have recourse to fusible metals. Gray iron from phosphorus, sulphurous, silicious, and clay ores, is of this kind; as well as pig iron from the same ores, smelted by heavy burden. Cinder compositions will not improve metal obtained from calcareous ores, or that smelted by an excess of limestone, or by a too light burden, for, though it should melt, and become apparently very liquid, it will "come to nature" so soon that no time will be afforded for improving it.

In a previous chapter, we remarked that the best policy which the iron manufacturer can pursue, is to make cheap pig iron, and leave improvement in quality to the puddling furnace. This is perfectly true within certain limits. But, if we adopt the most economical plan of working the blast furnace, that is, by carefully preparing the material, and by carrying as heavy a burden as possible, these limits are very extensive. When these conditions are observed, good iron may be produced with comparative ease. But pig iron, from furnaces where the manipulations are carried on irregularly, and where change of ore, coal, burden, and workmen often occurs, is with difficulty improved. In most cases, it is better to run this iron through the finery, and make of it coarse bar or railroad iron, than to attempt to improve it in the puddling furnace. Careful manipu-

lation in the blast furnace is the best security of success in the puddling furnace; in fact, success in the one is in exact proportion to the economy observed in relation to the other. The truism that good work is always eventually the cheapest is in this case amply confirmed.

We have also attempted to explain what kind of iron can be made from a certain kind of pig metal, and to show what kind is necessary for specific purposes. So long as the process of puddling is imperfectly understood, the qualities of bar iron may be said to depend on metal, fuel, and labor; for, practically, it is evident that the product will depend on the quality of the materials we possess. At this, if at any stage, in the manufacture of iron, scientific improvements are available. Industry and attention are sufficient, in most cases, to produce satisfactory results; but in puddling, something else is required. Every experienced iron manufacturer is convinced that the quality and quantity of iron produced depend upon the nature of the cinder employed. That, in blast furnace operations, cinder can be improved only to a very limited degree, we have already shown. But, in the puddling furnace with iron boshes, this improvement may be indefinitely extended.

It is of but little use to attempt to make scientific improvements at the charcoal forge. At this fire, the best and most easy method of making excellent iron is by employing white metal of good quality. The same remark is applicable to the puddling furnace with brick or soapstone lining. Cinder compositions are, in these cases, unavailable. These are of advantage only in the puddling furnace with iron bottom and boshes; and it may be said that there would be no limit to improvement in the quality of iron, if the iron lining would permit of a heat sufficiently strong to melt the refractory metals. But because this is not so, we are confined to metals which melt at a given temperature; and for this reason, also, the irregular nature of the metal we employ produces such unsatisfactory results. The following statements apply to furnaces with iron boshes; and deductions may be drawn from them relative to refining or puddling.

h. In puddling, the most simple method of improving iron is, as we have previously mentioned, by mixing different kinds of metal on the same principle we have applied at the blast furnace. The obvious deduction is, the more kinds we mix, the better the result, which coincides exactly with experience. For this reason, it is advantageous to mix pig iron from the coal regions with iron smelted from primitive or transition ores, and to mix calcareous metal with a silicious or phosphorous pig iron. Stonecoal or coke iron is greatly improved by being mixed with charcoal iron. Baltimore pig iron, in itself an excellent iron, would, if mixed with iron from Hanging Rock, Ohio, be made a still better article. The latter may be considered the best metal in the world for castings; but, associated with the former, it would make a very superior wrought iron. In this matter, it is necessary to guard against the opinion entertained by some, that the mixture of iron from different localities merely is sufficient. This is by no means the case. Mixing is to be performed with due relation to the chemical composition of the ore, to the place at which the metal is smelted, and to the fuel applied in smelting. Magnetic and bog ores work well in the blast furnace, and their respective metals work well in the puddling forge. Calcareous ores and those containing manganese work best in the blast furnace, if smelted along with silicious or clay ores. The metals derived from each of these ores will make, when mixed, far better articles in the forge than each would produce, if wrought singly.

Another method of improving iron is by mixing the cinders produced by separate furnaces. This method is extensively practised at the Western establishments. The kind employed is puddling cinder from furnaces which work refined metal, and cinder from charcoal forge fires. Such cinder is charged along with the pig iron in the boiling furnace. After the iron is melted, hammer slag or roll scales are employed to excite fermentation, as well as for the purpose of accelerating the work, and improving the quality of the iron. The application of cinders, notwithstanding their unquestionable utility, is

very limited. Inferior pig iron requires good cinder in large quantity; the use of cinder, therefore, is restricted to charcoal iron; and even here it can be applied only in a very limited degree. In this respect, the Eastern do not enjoy the advantages which the Western works possess, on account of the charcoal forges and charcoal iron of the latter, and the extensive use which the former make of anthracite pig iron. If the cinder employed is of good quality, and in sufficient quantity, our labors cannot fail to be successful. But in the stonecoal regions, good cinder is not abundant; and that obtained even from the best forges is only of medium quality. Where hot-blast iron is refined, it is so inferior as to cease to be of any use. The cinder we require should be obtained from pig iron from the richest ores; and we may work to the best advantage by observing the same rule in relation to it which we gave relative to the mixing of pig iron and iron ores.

A better method of improving iron than the application of cinders is by the addition of ore to the iron charges. This is extensively practised at the Eastern works. The ore is either put in large pieces around the inside of the furnace to protect the boshes, or charged in small fragments with the metal, like the additions of cinder. What kind of ore is best adapted for this purpose is in some degree a scientific question; but experience shows that none answers so well as magnetic ore; and this is generally employed. If magnetic ores cannot be obtained, and if it is necessary to employ oxides, or hydrates, it is advisable to burn the latter hard, and to convert them into a black magnetic oxide, before we use them. The leading principle which guides us in the selection of an ore is its amount of iron and its purity. Sulphurous, phosphorous, and calcareous ores will of course be rejected. Unless the amount of iron in the ore is greater than that in the cinder we are making in the furnace, we shall fail to realize the advantage we expect. If there is more foreign matter in the ore than the cinder generally contains, we shall obtain iron in smaller amount, and of worse quality, than though no ore had

been added. The best cinder from charcoal forge iron contains scarcely more than eight or ten per cent. of foreign or silicious matter; the residue is iron and alkaline substances. The amount of silex varies from ten to thirty per cent. and even more; and its increase beyond ten per cent. is inversely proportional to the quality of the iron. This shows clearly what is required for the improvement of iron; that is, alkalies and metallic oxides. Alkaline earths, such as lime, magnesia, and baryta are not adapted for this composition, because the temperature of the puddling furnace is so low that they will not combine with the silicious matter; and they injure the cinder, by stiffening it. An ore serviceable for puddling may contain manganese, clay, soda, potash, and silex; but if it contains lime, magnesia, baryta, sulphur, phosphorus, copper, silver, and more than twelve per cent. of silex, it must be rejected. The native magnetic ores are, under all circumstances, preferable. At Lake Champlain, and in Essex County, New York, an abundance of suitable ore exists. New Jersey contains a quantity of ore which, though very silicious, is well adapted for our purpose. In Missouri, Wisconsin, and in other States, such an ore appears to exist in abundance. But, in the anthracite and bituminous coal regions, the iron master is placed in a somewhat difficult position. The richest hydrates of Huntingdon or Lebanon County, in Eastern Pennsylvania, or those from the Cumberland River, Tennessee, may serve as fluxes; but they must be converted, by roasting, into magnetic oxides, before they will serve for the improvement of iron. Magnetic ore of good quality will, of course, serve as well as hammer-slag for boiling, that is, for raising the cinder.

Though the application of cinder and iron ore rests upon sound principles, it is still limited to certain qualities of metal, and never produces anything beyond a certain kind of bar iron belonging to the cinder we are able to generate from ore. We are thus sometimes left in a difficulty, if we expect a kind of bar iron which it is beyond the capacity of our cinder or ore to furnish

us. In nearly every instance, artificial fluxes are the safest and cheapest of all fluxes, and, when intelligently applied, produce results which we have yet failed to derive from any cinder or ore.

The materials suitable for these artificial compositions are very limited; and their application requires experience. The kind of material used is of less consequence, in the results obtained, than the manner in which it is employed. Caustic potash, caustic soda, manganese, iron, and clay may be employed with advantage. All other matter, even carbonates of potash, is useless; lime and magnesia are injurious. Soda is preferable to potash. We are, therefore, reduced to soda, manganese, and clay, as the only available substances not already contained in the ore] except additions already noticed. [In many instances, pig iron contains an amount of manganese which renders the application of any additional quantity superfluous. The materials, then, at our disposal—in fact, the only ones we need—are soda and clay. In some cases, common salt or borax is useful. But, under all circumstances, whatever matter we employ should be mixed and ground as fine as possible. Our own experience has taught us that, unless this is carefully attended to, success is somewhat problematical. For this purpose, rotary iron barrels, like those employed in foundries for grinding charcoal, are employed. The materials are mixed in definite proportions. A small fire is kept under them to dry the clay, and mix the soda intimately with it. The contents are then ground into an impalpable powder, which must then be placed in a dry, warm place for preservation. When moist, even though under the influence of a dry atmosphere, its virtues are greatly diminished. To illustrate the operation of artificial fluxes, we shall relate our own experience in regard to the different kinds of pig iron for which they were employed, and indicate, as we proceed, the various compositions which we tested. We shall present, at first, the most simple cases, and gradually ascend to those which are more complex.

1. Metals smelted by charcoal from phosphurets. It

is immaterial to what degree this iron may be cold-short, provided it is mottled or gray pig, or the result of heavy burden. By a judicious application of Shafhautl's compound—that is, five parts of common salt, three of manganese, and two of clay—it will produce an excellent bar iron, equal to any iron from the best charcoal metal. The clay alluded to is not a silicious, sandy, white matter, or common loam; but the finest white plastic clay, which, when wet, is very tough, and when dry, of smooth appearance; it forms an impalpable powder. The pig iron is heated as in common operations. It is melted down by a rapid heat; the damper is closed; and the cinder and metal diligently stirred. In the meantime, the above mixture, in small parcels of about half a pound, is introduced in the proportion of one per cent. of the iron employed. If, after this, the cinder does not rise, hammer-slag may be applied. Where competent workmen are employed, a good furnace will make a heat in two hours, and furnish highly satisfactory results. Where the operation is well conducted, there will be neither too much nor too little cinder in the furnace. From a rolling mill of which we have personal knowledge, containing six double furnaces, not even a wheelbarrowful of cinder was carried away, while no cinder, in addition to the roll scales, and the cinder supplied by the furnaces, was added.

2. Pig iron, from sulphurous ore and heavy burden, smelted by charcoal. The appearance of this metal is very black. Under ordinary circumstances, it produces very red-hot iron. It was melted and wrought by the same method as No. 1, with this difference, that, instead of clay, chalk was employed. In the furnace, it worked somewhat faster than the above, but always produced an iron inferior to it.

3. Gray charcoal iron, of any cast or mottled iron, will produce with great facility, by working it in the same way as No. 1, a superior fibrous iron; but great industry is required to make as fine and strong an article No. 1.

4. Gray anthracite iron, if free of sulphur, requires

the mixture of No. 1; but if it contains any trace of sulphur, No. 2 will answer better. This remark also applies to gray coke iron. But coke iron is less easily wrought into a good article than anthracite iron. Neither works so well as charcoal pig. The main difficulty in working them consists in melting-in. But, by careful and industrious manipulation, we shall arrive at as satisfactory results as with charcoal iron.

5. From white iron of small burden, or from an excess of limestone or manganese, it is useless to attempt to produce a good article. A small amount of such iron, containing phosphorus or sulphur, will make a whole charge cold-short, or hot-short, and it is impossible to remove silex from it. By the addition of a very small portion of soda and clay, the better kinds of such iron may be advantageously puddled. If caustic soda is not too expensive, it may be considered preferable to common salt. One pound of soda and one pound of clay are sufficient for 500 pounds of iron; or, if caustic soda is not applied, two pounds of common salt. All inferior and irregular metals, whether charcoal, anthracite, or coke iron, should be sent to the refinery, melted into finery metals, and puddled in furnaces with brick or soapstone lining, in which operation a small addition of clay and soda will be found advantageous. From these demonstrations, we see of what importance pig iron, which melts and keeps liquid for a given length of time, is to puddling establishments. Such iron is produced only by blast furnaces which carry heavy burden and consume a very limited amount of fuel.

6. In puddling manipulations, we must be careful that the furnace hearth is kept tight, and that the cinder does not leak through the bottom even in the strongest heat. A heat which loses its cinder is spoiled. The quality and quantity of the metal are injuriously affected. The amount of cinder required in the furnace depends upon the metal we use, upon the competency of the workmen, and upon the iron we design to make. Good puddlers will work to advantage with a small quantity; but poor workmen require an abundant supply. With

a small quantity, the work is accelerated. Inferior requires more cinder than good pig iron, and gray more than white. If we desire strong iron, of fine fibre, we must employ gray pig of a fusible nature. By diligent work, without adding any scales or hammer-slag to the mixture, No. 1 will furnish an iron of unsurpassable absolute strength.

If we desire to make wire iron, it is necessary to employ gray pig containing a large amount of carbon, and flux it by means of caustic soda and clay. If expense is no object, borax may be employed with even greater advantage. In this instance, a fine-grained iron, of steel fracture, but softer than steel and harder than fibrous iron, is required. Fibrous iron is not adapted for the manufacture of wire. It does not draw well, and is not so strong as iron of a fine-grained nature. Such iron should be free from impurities and cinder; for these not only weaken it, but make the wire short and unclean, besides working hard on the draw-plate. To remove these impurities, we require a very alkaline, but at the same time very fusible cinder. Such a cinder will make a fine compact iron, exhibiting no fibres in the rod or billet, but only in small wire.

k. The height of the furnace top, or arch, from the bottom, varies, according to circumstances, from eighteen to thirty inches. In puddling furnaces, from eighteen to twenty-four inches; and in boiling furnaces, from twenty-two to thirty. The latter is the extreme, and seldom applied. Inferior pig iron which melts easily, and keeps liquid, requires a higher arch than pig iron of good quality. Gray metal produces better iron by a high than by a low top. White metal of any kind works more favorably by a low arch, for which reason it is puddled, and not boiled. A high arch works more slowly and consumes more fuel than a low arch, but the yield is superior both in quantity and quality. Wire iron requires a strong heat, but a high top. Good puddlers will work with a low arch; but such an arch cannot be intrusted to inferior workmen.

l. The depth of the bottom, that is, the iron bottom

below the door-plate or cinder-plate, is as variable as the roof. From four to six inches is sufficient in a puddling, and from six to twelve in a boiling furnace. In some cases, the latter is rather too great a depth; and even eleven inches may be considered the extreme. A deeper hearth is required for bad than for good pig iron. A deep bottom consumes more fuel, and requires greater attention, than a flat bottom, but it makes better iron, and yields in larger quantity. A large body of cinder does not make very fibrous, but very clean iron.

m. The dimensions of the grate of a puddling furnace depend upon the size of the hearth, and upon the kind of fuel employed. For wood, in small chips, a grate whose size is in the ratio of one foot to twelve feet of hearth, is sufficiently large; for bituminous coal like that of the Pittsburg vein, one foot to four. For hard and impure coal, it may be extended to half the size of the hearth. But where blast is applied, as in the case of Pennsylvania anthracite, these rules must, in some measure, be modified. However, if we have any doubt about the matter, it is better to make the grate too large than too small. The only disadvantage of a large grate is that it consumes a greater amount of fuel than one of the proper size.

n. The influence of fuel upon the quality of the iron manufactured is not remarkable; but, in some instances, it is important. Sulphur and phosphorus do not appear to have any influence whatever upon the iron in the furnace, for we have experienced no difficulty in puddling with sulphurous coal or turf, the latter of which generally contains phosphorus in admixture. Wood undoubtedly affects the process very favorable. We have observed very closely two establishments in which the same kind of metal was puddled by wood and by inferior anthracite; the abilities of the workmen about equal. The iron puddled by wood was strong, white, and of fine fibre. That puddled by anthracite was equally strong, but dark in the fracture, and of coarse fibre. In the blacksmith's fire, the superiority of the former was still more apparent. The only reason which can be as-

signed for this difference is the difference in the composition of the ashes of the wood and anthracite. Wood ashes are of an alkaline, the ashes of anthracite are of an acid, nature. With wood or bituminous coal no difficulty is experienced in puddling, on account of the ashes; but with anthracite, the ashes have at times proved a serious obstacle. The application of blast, and the use of large grates in the modern anthracite furnace, have, in a great measure, removed this obstacle. Anthracite iron, though sufficiently strong and malleable, is frequently of so dark a color as to be unfavorable for blacksmith's use. This color is imparted by the ashes carried over from the grate upon the hearth. These ashes, which are not pure earth and silex, contain a large amount of carbon. If they cover the surface of the exposed iron, carbon will be inclosed in the balls. The silex is then absorbed by the protoxide of iron, and a black cinder is formed; when, to this, black carbon is added, it is not strange that the iron becomes dark in the fracture. The most effectual preventives of this are quick work, and an abundance of very fusible cinder. Still, it may be stated, as a general rule, that iron puddled by a small amount of cinder, and by the application of stonecoal, no matter of what kind, is of dark fracture. If more cinder is applied, the same pig iron will exhibit a brighter fracture.

o. Heating stoves attached to puddling furnaces are, where fuel is expensive, and where competent workmen are employed, a valuable appendage. By their, use, a quarter of an hour or more is saved each heat. Where they are used, it is advisable to give the metal only a cherry-red heat, and to keep it in the stove as short a time as possible. The best situation for a stove is between the pillars of the stack. Stoves designed to heat the pig iron beyond a cherry-red heat, or even to melt it, are not advantageous in the way of appendages.

p. The yield depends very much on the nature of the metal and upon the mode of working it. In puddling good white metal, there is a loss of four or five per cent. With bad white metal the loss is twenty per cent.,

and even more where we seek to improve its quality. Gray pig metal, of whatever quality, may, by a judicious application of ore and artificial fluxes, be made to yield from ninety-five to ninety-eight per cent. of rough bars per 100 cent. of metal.

General Remarks on Refining.

The run-out fire—finery—is, as we have previously remarked, an imperfect apparatus. Its design is to improve the quality of pig metal, and to diminish the labor of converting it into wrought iron. This design is partly accomplished; but the apparatus is still far from being complete. It is not our object, at present, to suggest any improvement upon it, but simply to define its purpose, and to exhibit its imperfections.

At the time coke iron was first made, a large quantity of bad iron was, as might have been expected, produced in the blast furnace. Such metal, of course, worked well neither in the charcoal forge nor in the puddling furnace. In such a case, but little could be expected from the run-out fire; because then the nature of the charcoal forge and of the puddling and blast furnaces was not well understood. But this offset to imperfect results cannot now be so successfully pleaded by the manufacturer. Gray pig iron from a well-conducted blast furnace operation can be puddled to the best advantage, without refining; and it is generally admitted that such iron is of superior quality. In addition to this, experience shows that it is cheaper than refined iron. Therefore, the only iron left for refining is that which results from badly-conducted blast furnace operations. That the run-out fire is not the best apparatus for effecting that result, is sufficiently proved by experience; but theoretically, the fact may easily be demonstrated.

If ore is once reduced to iron, the result may be a very imperfect metal. Still, the largest amount of matter in it is iron. In the crude metal, it is seldom less than ninety per cent. This element is, in all instances, the same; it is as favorable in bad as in the finest metal,

with the exception of being adulterated by some admixtures which, under certain circumstances, are injurious.

If such metal has been properly treated in the blast furnace, we find no difficulty in producing from it a good wrought iron. But if badly managed, it is almost impossible to obtain this result. The abundance of bad iron in the market is a proof that the finery accomplishes but a slight improvement. The main difficulty in working pig metal smelted by a high heat in the blast furnace consists, as we have before explained, in the impossibility of so completely dissolving it as to enable the cinder to act upon the foreign matter in it to advantage. In most instances, it readily dissolves by a tolerable heat ; but the cohesion of its particles is so great, and its affinity for oxygen so strong, that it does not remain liquid sufficiently long for the removal of its impurities. The objections made against cold boshes in the puddling furnace apply with greater force against the finery fire, for in the latter cold boshes not only exist, but are in a less advantageous form than in the double puddling furnace. Therefore, the finery fire effects scarcely any improvement in the quality of iron, and is, of course, not adapted to produce cheap work.

The chief purpose of the run-out fire is the manufacture of a more uniform metal than is produced by the blast furnace. By bringing the metal to a somewhat uniform quality, we are enabled to secure more regular manipulation both in the forge and in the mill. But this advantage can be arrived at in a more perfect manner by very different methods. Another advantage it is said to possess is, that it does not consume so much iron, in neutralizing the silex of the pig metal, as the puddling furnace. This is true ; but if the run-out fire works by coke, which is generally the case, all the ashes of the fuel are saturated by iron, and a large quantity of the sand which forms the bottom of the fire. These objections are of a practical nature. We know that it is vain to attempt to improve radically bad metal by running it through the finery. We know, further, that this is not the method of making cheap iron. The finery fire will

waste from six to fifteen, and even twenty per cent. of metal. We may say that ten per cent. of this is, on an average, uselessly lost; for, in the puddling furnace, we can produce a yield equal to that in the finery, whether the metal is refined or not. This loss—without considering the wages of workmen, from one dollar to one dollar and fifty cents, and the expense of fuel, which for coke is seventy-five cents, and for charcoal two dollars and fifty cents—amounts to four dollars per ton of iron, that is, if we estimate the iron at but two cents per pound. The expenses of refining therefore, in the most favorable case, amount to at least five dollars and a half per ton.

In the following pages, we shall endeavor to point out still more completely than heretofore the deficiencies of the run-out fire; and for the purpose of assisting inventive genius, we shall add the different methods of refining at present practised in various parts of the world:—

a. 1. By charging to excess, in the blast furnace, ores containing phosphorus; these will produce white metal with the least injurious admixtures. 2. By casting the pig iron directly from the blast furnace in iron moulds, and cooling it suddenly by a current of cold water. 3. By running the melted iron into a mass of cold water. 4. By the making of rosettes, practised in Styria, and already described, an effectual method, unless the metal is very bad. 5. By tempering the metal; this is done by exposing it for twelve or twenty-four hours to a cherry-red heat. 6. By refining the iron in the blast furnace before tapping; this is effected by turning the blast upon the hot iron, and in this way burning impurities and carbon. 7. By feeding good ore, hammer-slag, or wash iron at the tuyere. Wash iron is the fine grains of iron gathered by pounding the furnace cinder, and washing it in a current of water; the water carries off the sand of the cinder, and the grains of iron left amount, in many instances, to six or seven, seldom less than three or four per cent. of the cinder. This method is extensively practised in Western Germany, where poor silicious ores are smelted. 8. By melting the pig iron in the

common charcoal forge, and by chilling it in water, preparing it for the following operation. A division of labor is thus practised in the same apparatus. 9. By melting the pig iron in a reverberatory furnace, and by blowing upon it, as practised in this country and elsewhere ; or by "washing" the melted metal with ore, hammer-slag, or other ingredients, to make it white. Of all the methods described, of all that are known, none is so well adapted to improve iron as the puddling furnace. The most useful in the above enumeration is the refining of the iron in the blast furnace before it is let out ; but this method is not generally applicable, and it would not answer at all in an anthracite furnace.

A method of improving iron, commonly employed, is by immediately cooling the hot metal in iron moulds, or by the application of water. Generally, both means are resorted to in the same case. As far as the removal of impurities is concerned, no improvement is effected ; for the iron contains as much silex, carbon, and sulphur after it is chilled, as before. Still, the manipulation is productive of great advantage. We shall endeavor, in a future page, to explain the nature of this curious process. Metal designed for the forge should be cast in iron moulds, if for no other purpose than to keep it free from sand.

Of late years attempts have been made to remove impurities by galvanizing iron ; but such experiments have not as yet been productive of any practical utility. What may be done, is not always profitable in business.

Theory of Refining and Puddling.

We now proceed to the examination of a subject which is no less difficult than interesting. It unfolds to us the nature of the material with which we have to deal, and shows us to what extent we can succeed in improving the quality of metal by converting it into wrought iron. We shall probably succeed in conveying a better understanding of this subject, by pointing out the nature of pig iron and wrought iron.

a. The chemical difference between cast iron and wrought iron consists principally in the difference of degree in which foreign matter is present in each; which is in larger amount in the former than in the latter. We should be cautious not to infer that this rule is universally true; that is, by applying it to iron from different sources. This rule is applicable only to a given cast iron, and to the wrought or bar iron which is made from it. There are many cases in which wrought iron contains a larger amount of impurities than cast iron, and yet is malleable; while cast iron of the same composition may be very hard and brittle. Berzelius, a celebrated Swedish chemist, tells us that he detected, in a certain kind of bar iron, eighteen per cent. of silix; and that this iron was still malleable and useful. One-tenth of that amount of silix will make cast iron brittle. The foreign matters generally combined with pig iron are carbon, silicon, silix, sulphur, phosphorus, arsenic, zinc, manganese, titanium, chrome, aluminum, magnesium, and calcium. Each of these tends to make iron brittle. Therefore, in converting cast into wrought iron, it is necessary, as far as possible, to remove them. Carbon, and, as far as we can judge, all other foreign matter, divide the crude iron into two very distinct classes. In the one, carbon is only an accidental mechanical admixture; in the other, it is in definite chemical combination with the iron. To the former belongs gray and more fusible iron; to the latter the white iron. Judging from the behavior of the different metals in the refining and puddling process, we are inclined to believe that the presence of silicon and silix has a similar influence, for it is almost impossible to remove silix from white metal with which carbon is chemically combined. The silix is present very probably in the form of silicon. This accounts for the great difficulty of improving such metal by any refining process. The same remarks apply to phosphorus and sulphur. White metal of small burden may contain from five to nearly six per cent. of carbon] as in the case of spiegeleisen smelted from spathic ores of certain character, and from our New Jersey Franklinite

ore; [and if smelted from poor ore, almost an equal amount of other foreign matter, such as silicon. Upon the presence and form of these, its white color and crystallization, in a great degree, depend. Gray pig iron seldom contains more than 4.75 per cent. of carbon, and generally only from 3.50 to 4 per cent. When carbon is present to the amount of but two to three per cent., it becomes white. We know, from experience, that white iron of heavy burden behaves well, and that it can be greatly improved in the puddling furnace; but with less facility in the charcoal forge. We also know that it is almost impossible to improve white iron of poor origin, and light burden, containing carbon in large amount, by any method of manipulation. If the presence of carbon were the only difficulty to be overcome, we should not despair of working it advantageously. In fact, the better kinds of this metal are worked with success in the charcoal forge; but in this forge the poorer kinds will not work at all. In the puddling furnace, the former will produce a good article, though not equal to gray metal from the same ore; but the latter will yield a very inferior iron. Hence, we conclude that, in this metal, silex is present in the form of silicon, and that it is chemically combined with the metal as an alloy. This remark also applies to calcium and phosphorus. By these combinations, the difficulties encountered in our attempts to remove impurities from metal are explained. Were carbon the only difficulty against which we have to contend, the metal could be made to work well in any apparatus. Were the protoxide of iron the only base in the cinder, this of itself would absorb any amount of oxidized silicon or silex. But, in consequence of the change of silicon to silex, the former must first absorb oxygen; and this it can absorb only from the protoxide of iron in the cinder. The silex, thus forming, will attract three atoms of iron in absorbing oxygen. The oxygen, in turn, will form very adhesive white iron, which crystallizes rapidly. Its crystals include carbon, silicon, and even silex. In this instance, we require a far larger amount of oxygen to remove impurities than in the case of gray iron; and

this oxygen can be derived only from the oxygen of the cinder, or, from the protoxide of iron which the cinder contains; or, where the cinder is very alkaline, from magnetic oxide of iron. Hence, it follows that, to saturate the silex formed, an immense quantity of iron is taken from the metal itself, to be oxidized by the atmospheric air. This oxidation raises the temperature of the metal, and separates the carbon before the remaining impurities can be effectually removed. The only method of improving such metal is to melt it by a very high heat, and under cover of a very strong alkaline cinder. But this is not feasible either in the charcoal forge or in the puddling furnace.

b. In composition, wrought iron is frequently inferior to the metal from which it is made; that is, if we apply the term *inferior* to the preponderance of foreign matter which it contains. Wrought iron containing a large amount of silex and carbon, especially the first, and even a given proportion of phosphorus, may still be a good bar iron. The main difference between pig and wrought iron consists in their mechanical structure or aggregate form. Pig iron is a homogeneous mixture of impurities and metal, in which, by affinity, atom is brought close to atom, and in which a transformation from the mechanical to a chemical admixture is easily effected, as in the case of gray and white metal. Wrought or bar iron is a mixture of iron more or less pure with a mass of homogeneous impurities, or cinder—the latter filling the crevices between the crystals of the iron. If we remember that iron is fusible in proportion to the carbon it contains, we shall arrive at a very comprehensive conclusion. If we melt pig iron, and expose the cinder which surrounds it to the influence of oxygen, the carbon will evaporate, and iron of greater or less purity will remain. This iron, to be kept liquid, requires a higher temperature than at first; consequently, unless the temperature is raised, it will solidify or become granular. In this state of metamorphosis, its infusibility will increase, and after the expulsion of the carbon, it will contract into a solid mass under the highest possible heat. By stirring and mixing

the pasty iron, small grains are formed ; at first, on account of the partial fusing of the iron, in small particles ; but, as the fusibility diminishes, these particles unite by force of cohesion ; and the bodies thus formed may, by exposure to a higher heat, be welded together. The mixing of cinder and iron will prevent the latter from forming large grains. This result, of course, will be more easily prevented by diligent than by tardy manipulation. Where the pig iron is of such a nature as to keep liquid while the work goes on slowly, still better results will be afforded. This process is analogous to that of salt-boiling, in which, by stirring the brine, the formation of large crystals is prevented. If the "crystals" of iron thus formed cohere, they form, under the influence of motion, a porous, spongy mass, whose crevices are, if not filled, at least coated, with cinder. If these masses, which are the lumps or balls at the charcoal forge and puddling furnaces, are shingled or squeezed, the crystals of iron will not unite, but form coated cells with a film of cinder, of greater or less thickness, according to the fusibility of the cinder. Iron in a connected form, and cinder in separate cells, are thus blended in a homogeneous mass. The more this iron is stretched, the more it forms fibres. Fibrous bar iron resembles hickory wood, in the fact that it is a combination of fibres and spaces. In bar iron, these spaces are filled with cinder. When other circumstances are equal, the strength of the iron will be proportional to the fineness of the fibres. That portion of the iron which is not melted, which crystallizes too fast, or whose premature crystallization the workman cannot prevent, is in the condition of cast metal, and cannot be converted into fibrous wrought iron. In the puddling furnace, it is necessary to prevent crystallization by manual labor. This result, whether in the Catalan forge, the wülf's oven, or the German forge, is partly accomplished by the blast.

If the characteristic difference between wrought and pig iron] carbon excepted [consists in nothing else than such a well-regulated mechanical mixture of cinder and iron, we ought to be enabled to produce fibrous wrought

iron from any cast iron, whether it is or is not purified by the process we have described. This is actually the case. Very fibrous bar iron, which is strong and malleable, is made from very inferior metal in which no removal of its impurities is effected. Among other instances, which, we may observe, are very frequent, in which this result is accomplished, we may mention that, at Hyanges, France, very inferior metal is converted, by a cheap and skilful puddling process, into a very fibrous bar iron, of great strength and ductility. But this iron is puddled and reheated by the lowest possible heat; it is then rolled, and ready for market. For hoops, rails, and nails, it is a very useful article; but it is of no use to the blacksmith. Heated by any temperature beyond that of the puddling and reheating furnaces, it returns to its primitive state, in which condition it becomes worse than the cast iron from which it was originally made. None but a very skilful blacksmith can weld it; for, when slightly reheated, it falls to coarse, sandy pieces, or melts like pig iron. That which thus loses its fibrous texture in heating, the smith calls "burnt iron."

c. Wrought iron of a white color, fine fibre, and yielding when struck, a dead sound, is not liable to these alterations. It remains fibrous under all conditions, and is altered neither by heat nor water; that is, provided the heat is not excessive, or of too long duration. Such iron must be free of all carbon or elementary impurities, or its cinder be of such a nature as not to be altered by carbon or silicon. In Styria and Carinthia, iron of good welding properties, very fibrous, and remaining fibrous, however often it is heated or cooled, and very tenacious—in fact, a perfect sample of excellent iron—is manufactured from carbonaceous, spathic ores, which contain a large amount of manganese. Bar iron, from whatever source, if manufactured from metal smelted by a well-conducted process from ore containing manganese, is generally of the same character; at least, it is always the best for blacksmith's use. These facts show conclusively that manganese has a favorable influence upon

iron. Manganese has greater affinity for oxygen than iron; and its oxides are powerful bases, stronger even than the oxides of iron.

d. Iron, carbon, and silicon have a great affinity for each other, but, so far as we can judge, it requires a given temperature and certain conditions to develop a polarity sufficiently strong to blend them so intimately together that the specific quality of each is lost in that of the other. This is actually the case between carbon and iron; and it is rational to expect that it is the case between silicon and iron, as well as between iron, phosphorus, and sulphur. The latter two combine with iron at a low temperature. If such a chemical connection between silicon and carbon happens to exist in metal, it is evident that their separation must be a matter of extreme difficulty. Silicon has a stronger affinity for oxygen than either carbon or iron; for this reason, as well as for the large amount of oxygen required to oxidize the silicon, it is so difficult to remove it from the iron.

The amount of carbon may be very large in some kinds of metal, particularly those smelted from poor silicious ore, or those smelted by coke and anthracite, or as the result of light burden. If such metal is remelted in a puddling furnace, or in any apparatus in which there is access of atmospheric air, the silicon will absorb oxygen, should it exit. If, perchance, atmospheric oxygen, or, what is still worse, watery vapors have access to the metal, the temperature of the particles of iron is raised to such a height that a portion of carbon will evaporate. The metal, thus transformed, will, by its infusibility, inclose portions of metal which are brittle. The fibres of such iron we cannot expect to retain. If present in the rough bars, they will disappear when the iron is reheated. This result, theoretically deduced, coincides with practical observations. The fast working of such metal, when it is to be wrought in the charcoal forge, may be retarded by throwing sand on the partially refined iron. Sand dissolves a part of the iron which incloses the injurious particles, by forming with

it cinder; and gives the inclosed iron a fusible protection. It also retards, in the mean time, the too rapid absorption of oxygen. Such iron, of course, yields badly in the forge fire; the wrought iron which is produced from it will be inferior. Metal so impure should never be taken to the charcoal forge. In the puddling furnace, it is worked with but little advantage, though with greater success than in the charcoal forge. As previously remarked, puddling furnaces with cooled boshes are, in this case, of no use; for this metal requires a high heat, and a large quantity of cinder, to make it work slowly, to protect the iron and carbon, and gradually to oxidize the silicon. When it is worked by the addition of oxidizing cinders, or of water; or when it is melted slowly; or when oxygen has access to it, which happens if there is too small an amount of coal in the grate, the result is a bad article, and a poor yield.

In our investigations, we have invariably given preference to the white metal containing carbon in large amount. But when we consider its bad qualities, the fact that it originates from an imperfect blast furnace manipulation, and, finally, its relation to hot blast, we shall be justified in treating it as inferior to other pigs for this purpose.

Besides the white metal, composed of iron, carbon, and silicon, which may result from the very best ores, as is the case in the magnetic ore regions, there is white iron, with an admixture of phosphorus and sulphur. The latter is inferior even to the former, if the result of light burden. But the worst of all metals is that smelted from bad ores, and from an excess of limestone, and hot blast. In addition to carbon, silicon, phosphorus, and sulphur, which may be removed, this metal contains calcium and magnesium, the element of alkalis, which destroy every prospect of improvement with the ordinary means at present at our disposal. As we may meet with this metal; as its quality is of such a nature as, thus far, to have baffled the most acute ingenuity; and as it contains at least eighty-five or ninety per cent. of good iron, we shall suggest a method of improving

it, or of preventing the production of so large an amount of it as heretofore.

e. All metal smelted beyond a certain temperature, and produced under specific conditions, is white; often of a bluish color, if it contains the elements of the alkaline earths. We suppose that the earthy matters, silex, lime, and magnesia, are reduced to metals, and chemically combined with the iron. If we melt such iron with access of oxygen, it will of course be transformed into a pasty mass, because a part of it is not fusible, that is, it is already deprived of carbon, for this is the only element which can effectually secure fusibility. Silicon and calcium increase the fusibility of metal; but these are oxidized by the slightest exposure, and thus serve to diminish its fusibility, and in this way, as well as by the increase of temperature resulting from oxidation in the metal itself, destroy the carbon. If the carbon could be retained, it would tend to keep the metal liquid; it would thus offer a chance of acting upon the impurities. For these reasons such metal will work fast, unless we are desirous of improving its quality, which, with the better kinds of charcoal metal from rich ore and judicious blast furnace manipulations, is generally our object. But when we attempt to improve its quality, the metal works slowly, yields very poorly, and is seldom or never made to produce an article of tolerable value. We know, practically, the difficulties connected with such metal, and from facts we have presented, have deduced a rational theory, which, if judiciously applied, ought to show in what direction our attempts at improvement should tend. If, in consequence of oxidation, the metal becomes less fusible, and thus incloses impurities, a mechanical separation—that is, fast work and the application of strong cinder, the latter of which will keep the iron separate—ought to be a means of improvement. Such is actually the case. By the application of strong cinder where silex predominates, a dark fibrous bar iron is produced, which, when reheated, returns to a more or less strong cast iron, that is, a cold-short bar iron of a crystalline or granular fracture. This kind of puddling

is very frequently practised, especially in our anthracite region; but that which most clearly illustrates such work is the puddling process at Hyanges, to which we have so often referred. At that place, the pig iron is melted-in with a mixture of feldspar and squeezer cinder; in this the iron keeps pasty for a long time. By means of the feldspar, cinder of a silicious composition is formed which is very fusible; before the feldspar is melted, it is almost sandy. Its fusibility increases as the furnace becomes warmer, and as the work progresses. When its fusibility arrives at a point at which its utility appears questionable, the cinder is let off, and the iron, by this time ready for shingling, is quickly balled up, and taken to the hammer. Inferior pig iron may thus be worked to advantage; but its quality cannot be much improved. In this case, we see by what means a fibrous iron can be produced from a metal which, to all appearances, it is impossible to improve. But at the same time, it suggests the method by which improvements may be effected. It shows that an alkaline cinder is of no advantage in working such iron. As the removal of silicon or silex is the principal object at which we aim, the correctness of the method pursued in working white iron is somewhat doubtful; nevertheless, it is the best with which we are acquainted.

f. Metal whose quality is such as either to produce, if worked on a cheap plan, bad iron, or to produce it in such limited quantity as to make its application unprofitable, is said to be the result of too much heat in the blast furnace, or the effect of hot blast. Low temperature and cold blast do not make such iron, or, at least, not very frequently. Therefore, the cause of the difficulty lies chiefly in the conditions of the blast furnace. Before hot blast was introduced, such pig iron was generally the consequence of too wide a hearth. When it happened to be smelted, the furnace was blown out, and a new hearth put in. In this case, the cause of bad iron must be attributed to the absence of free oxygen in the hearth, as well as to an excess of fuel. Where cold

blast is employed, gray iron is made in a high, narrow hearth, and flat boshes; but where hot blast is used, it can be made in a low hearth, and steep boshes. Consequently, in the latter case, the heat is high up in the stack, for which reason the pig iron will contain a large amount of chemically combined impurities, and will become hard and brittle. Therefore, hot blast does not affect the iron in any other way than it is affected by cold blast and too wide a hearth. It is thus evident that the conclusion which most writers on this subject have arrived at, that a too high temperature is the only cause of the inferiority of the metal, needs qualification. That is to say, if, where the hearth is too wide, and the boshes too sloping, the same kind of metal is produced by cold blast which, under other conditions, is produced by hot blast, the conclusion that an excessive temperature occasions the bad metal referred to, is obviously erroneous.

g. The rule, that cinders are the criterion of the quality of the iron made, is in no instance more correct than in the present case. The removal of impurities, of which silex and silicon are the most injurious, is the main object in the refining of iron. Inasmuch as the principles of refining are the same, whatever is the substance with which we may be engaged, we shall confine our attention principally to silex. To remove silex, which is an acid, we require an alkali with which to combine it, and thus to form a vitrified, fusible slag. The greater the affinity in the slag for silex, the greater the amount of silex which will be removed. Therefore, in a forge cinder, we need as much alkali as we can possibly obtain, for upon the quantity and quality of this will depend the quality of the iron. Forge cinder from a charcoal fire contains more alkali than cinder from the puddling furnace. This accounts, in some measure, for the difference in the quality of iron which each produces. On close examination, we shall find, in this circumstance, the reason why the charcoal forge will not work inferior metals to advantage, and why the puddling furnace does not produce from good metal an article equal to that from the charcoal forge. The reason is

evident. Metals containing a large amount of silex, must, if we desire a good article, necessarily be partially converted into cinder; because good cinder requires a given amount of protoxide of iron to neutralize the silex which it contains. If the silex is not thus neutralized, the iron will be worse than the same metal from the puddling furnace; because, in addition to silex, we leave more carbon in the iron, on account of the presence and contact of charcoal. This makes the iron in the charcoal forge more cold-short than that in the puddling furnace. Intrinsically, it may be purer, but it is not generally more useful. In consequence of its bricks and coal ashes, consisting almost exclusively of silex, the puddling furnace cannot produce so good a cinder as the charcoal forge, in which everything can be kept free of silex. Therefore, the puddling furnace makes better iron from poor metal than the charcoal forge; but the latter makes better iron than the former from good metal.

To what extent the qualities of iron are connected with the composition of cinder may be understood by comparing one cinder with another. From a rolling mill in Firmy, France, a puddling contained 31.2 silex, 60.5 protoxide of iron and manganese, and 1.7 phosphorus. In this case we observe an immense quantity of protoxide of iron compared to that contained in blast furnace cinder. We also observe a diminution of silex, besides a large portion of phosphorus. Puddling cinder from Dowlais, Wales, consisted of 36.8 silex, 61.0 protoxide of iron, and 1.5 alumina. The first cinder is from charcoal pig iron; the latter from coke iron. Re-heating furnace cinder contains about 40 or 50 per cent. of silex, and often clay, in proportion to the sand used in making the hearth.

Charcoal forge cinder from a forge where good iron, though on a cheap plan, is manufactured—Hartz Mountain, Germany—contained 32.3 silex, 62.0 protoxide of iron, 1.4 magnesia, 2.6 protoxide of magnesia, and 0.28 potash.

The amount of protoxide of iron increases, and that

of silex decreases, in proportion to the quality of the iron. A cinder from a good iron in France consisted of 16.4 silex, 79.0 protoxide of iron, 3.0 lime, 1.2 alumina, and 0.6 protoxide of manganese. A Swedish cinder, from the softest kind of iron, was composed of 7.60 silex, 82.10 protoxide of iron, 2.80 magnesia, 1.10 alumina, and 6.80 protoxide of manganese. And a cinder from a strong kind of Swedish bar iron was composed of 38.5 silex, 44.4 protoxide of iron, 3.1 lime, 3.1 alumina, and 11.0 protoxide of manganese.

From these analyses of cinder, we deduce a leading principle which will guide us in directing the refining operations. The increase of alkalies in the cinder shows the method by which we must arrive at a good result. But it is necessary to guard against the very natural conclusion that the iron will be improved in proportion to the increase of alkali in the cinder. This is not the case, at least so far as the strength of the iron is concerned.

Pure iron, which is always soft, may be required for various purposes—as, for example, in the manufacture of cast-steel; but, in most cases, an impure, but fibrous iron is preferable. In making wrought iron, the main difficulty consists, not in producing fibres in the first stages of the operation, for this may be accomplished by almost every experienced manufacturer, but in retaining these fibres through every subsequent stage of the operation.

h. To form bar iron of a permanent fibrous structure, the cinder employed must be of such a nature as to resist the reducing influence of carbon and other unoxidized compounds of iron. Forge cinder is chiefly composed of protoxide of iron. One reason of this is that it is the nearest base at hand. Another is that the protoxide of iron, and the silex separated from the iron, are approximate at the moment of liberation, and, according to general laws, combine more readily than they would if once separated. Protoxide of iron is, under ordinary circumstances, with difficulty reduced to iron, particularly if once in chemical connection with silex;

but its reduction is possible, as is proved by the reduction of forge cinder in the charcoal forge, and puddling cinder in the blast furnace. We may expect that carbon, and in a still greater degree, silicon, contained in bar iron, will reduce the protoxide of iron in the cinder, and leave pure siliceous, or other matter; that it will, at any rate, destroy the vitrified texture of the cinder in the pores of the iron. A good cinder, of general application, would be one whose vitreous nature could not be destroyed by the influence of the impurities of the iron. A gray, glassy tough blast furnace cinder would be the best of all materials for this purpose; but it may be impossible to mix such matter properly with iron, or to mix with iron any glass which contains no metallic oxides, and which is not acted upon by reducing agents. The development of the nature of cinder will thus be the surest means of arriving at a correct understanding of the nature of bar iron. Carbon will reduce protoxide of iron from its combination. Therefore, for poor metal, the latter will not form a satisfactory cinder until all the carbon of the metal is destroyed. Where carbon remains in wrought iron, reheating will restore the granular texture of the metal. Any metallic oxide, forming glasses, which can be reduced to metal by carbon, is useless in the formation of forge cinders, for it would not serve to retain the vitrified character of the inclosed cinder. Protoxide of manganese is better than that of iron; it is only slightly affected by carbon; but silicon will reduce one part, and combine with another part of it. It forms an excellent glass, which resists the destructive agency of carbon. Iron manufactured by means of a rich manganese cinder is very strong, of good welding properties, and retains its fibres in almost any heat, and even when suddenly cooled in cold water. Besides manganese, the alkaline earths and the alkalis proper are the only substances at our service. Alkaline earths are of no use in the forge, for the temperature of the hearth is low, and sufficient time is not afforded for their combination with siliceous matter; they serve merely to stiffen the cinder, and add impurities that are injurious

to the iron. When present in large quantity, they frequently prevent the formation of fibrous iron. The alkalis proper, such as soda and potash, ought to be the best agents in forming a good cinder; still, experiments have not confirmed the conclusions which, theoretically, have been arrived at. Until the present time, no benefit has been derived from so apparently practicable a theory.

Bad pig iron contains carbon, silicon, and calcium, which should be partially removed; or, if not removed—which, in some instances, is unnecessary—we should employ a cinder which, mixed with any metal is not affected by the reviving properties of the impurities. If we melt such pig iron, and add to it carbonate of potash or of soda, it cannot effectually remove protoxide of iron from the cinder; it serves the purpose of simply making the cinder more fusible; it dissolves the oxides of metals, but it does not dissolve silex, lime, and magnesia; it will augment the fusibility of a strong alkaline cinder, and to this extent promote vitrification, but it cannot prevent the formation of protoxide of iron. Caustic potash or caustic soda is evaporated in the heat of a puddling furnace, before any union with silex can be effected. Potash and soda, mixed, are of greater advantage, for they offer a stronger resistance to the action of the heat; but our own experiments have convinced us that even these are inapplicable, because the greater part of the alkalis is lost in evaporation. Were it practically possible to make a cinder composed of potash, soda, and silex, and mix it with any kind of metal, however bad it may be in our estimation, the bar iron resulting would be strong, its fibres durable, and it could be welded with ease. But it would lose its strength, in proportion to the oxidation of its foreign matter, that is, the matter originally combined with the metal.

From these statements, we infer that the application of manganese is the best means of improving the quality of wrought iron. To what extent this improvement may be applied, has been already explained. It will, we hope, be more clearly understood from the following considerations deduced from experience:—

k. When a heat is drawn and shingled, the furnace must be so uniformly charged as to prevent the remelting of any portion before the melting of the rest. This is accomplished by a repeated turning and moving of the iron. The melting of the cinder before the iron becomes soft is a disadvantage, for when the cinder covers the fragments of iron, the difficulties of breaking the iron and mixing it with the cinder are augmented. The most favorable results follow when the iron and cinder melt together, that is, when both become pasty at the same time. It is of less consequence when pig iron is the more fusible than when the reverse is the case. To produce this state of things is sometimes a difficult matter; still, upon its accomplishment, success mainly depends. This difficulty is augmented by the fact that the composition of the cinder is not a matter of indifference. We can increase or diminish the fusibility of a cinder by adding to it an alkali, or silex; but this may injuriously affect the iron in the furnace. White metal is very apt to make a strong alkaline cinder, rich in protoxide of iron; this cinder will not melt sooner than the iron melts. In such cinder, poor white metal works too fast; sufficient time is not afforded for the metal to dissolve. Besides, it contains too large an amount of oxygen, or protoxide of iron; and the metal, by means of silicon and carbon, is converted into an infusible white iron. In such cases, a cinder which contains just so much silex that its fusibility will be increased by the application of an alkali is preferable, and therefore it is advisable the lining of the furnaces should be of fire-brick or stone. Such cinder will increase in toughness, at first, because the first matter liberated from the metal is silex; and the addition of silex to a silicious cinder will retard its fusibility, and afford more time to work the metal. In this, also, we perceive the utility of charging the iron along with the cold cinder. Any rich cinder will afford oxygen to the melting metal, but the application of it in too large amount will accelerate the work beyond the limits of prudence. White metal, especially that which is

not to be improved, ought to be melted-in without any cinder; but the grayer the metal is, the longer it remains fusible, and the greater may be the amount of cinder which can be charged along with the cold iron.

When the iron is properly melted down, that is, when it does not rise, or exhibit crystallized particles, we may accelerate the work by throwing in good iron ore finely powdered, roll-scales, hammer-slag, chemical compounds, water, or, in fact, anything which experience has shown tends to consummate the desired result. The matter thrown into the furnace, at this stage of the operation, will determine the quality of the iron which is made. If we desire to make hard iron, we should leave a certain amount of silicon and carbon in the iron; and if, at the same time, we desire to produce fibrous iron, we must be very cautious in relation to applying anything of an oxidizing nature. Neither hammer-slag, manganese, water, nor any kind of iron ore is applicable. Active manipulation, and a furnace that is not too warm, will produce a hard, strong, fibrous iron of a dark color, but not adapted for blacksmith's use. By the introduction of hammer-slag, roll-scales, or magnetic iron ore, a purer iron may be made. Of these, magnetic ore is the preferable. Hammer-slag and cinder always contain the greater part of the impurities of the iron from which they are derived, especially sulphur and phosphorus. Cinder is the very element which removes impurities; hence, if we introduce an impure material, we cannot expect a pure article of iron. Cinder has only a limited capacity for sulphur or phosphorus; but this increases proportionally to the amount of alkali added to it. Therefore, even though we introduce a very alkaline cinder, such as hammer-slag, roll-scales, and forge cinder, which may have been obtained from a very good iron, still, in a puddling furnace, its capacity for impurities is diminished, because a large portion of the alkali is absorbed by silex. In this way, we may spoil our iron in the furnace with the very material we employ for its improvement. This unfortunately too often happens. Magnetic iron ore serves all the purposes of hammer-slag; and if

it can be obtained in purity, free from sulphurets, it is by far the safest of all means for improving iron. To the manufacturers of the East, vast quantities of magnetic ore from Lake Champlain, or New Jersey, are at all times available. By the application of good ore, and by the observance of sound principles of manipulation, we may obtain iron applicable to all our common wants. In this way, merchant iron of the finest quality may be made.

If it is our intention to make a very superior iron, neither magnetic ore nor hammer-slag will be of much service; in fact, they are, in a greater or less degree, injurious. The reason of this is that, in a very alkaline cinder, the solvent power, for the magnetic oxide, is rather small; hence, a given portion of the flux is left undissolved; this, as an isolated matter, will be visible in black spots and grains, darkening the fracture, and adding nothing at all to the strength of the iron. In addition to this, it produces coarse pores, which, for fine polished work, are injurious. A fine, superior iron, of great cohesive properties, requires a very alkaline, well-fluxed but not too fusible cinder—a cinder free from all mechanical admixture, or imperfectly dissolved matter. An alkaline cinder is required, to remove impurities from the iron, and a well-fluxed cinder to form fine fibres. These conditions are fulfilled in the charcoal forge only with the best kinds of metal; in the puddling furnace only where the lining is of iron, and where very fusible gray pig is employed. Carbonates of the alkaline earths require the heat and time which a blast furnace affords to be of any service; and the carbonates of potash and soda are not only expensive, but they are weak solvents. Borates are, of all fluxes, the most perfect, but of a carbonizing, reducing character; therefore, borax is a most powerful reducing agent. In the puddling furnace, it produces a very pure, but carbonized iron. Phosphates may be considered the most perfect of fluxes in puddling. The fear which prevents some iron manufacturers from placing phosphorus in connection with iron is without foundation in theory or practice. Our own experience

and that of others prove that there is not the least difficulty in removing phosphorus from iron, or even in smelting iron ore containing phosphorus, without injury to the metal, that is to say, provided carbon has not been present in so large an amount as to leave phosphoric acid undecomposed. Much carbon is required to decompose phosphoric acid. In the puddling furnace, phosphates cannot be decomposed, and they remain as a solvent for cinder of a very alkaline nature. Any free alkali, in the presence of carbon, will abstract phosphorus from iron ; so, also, will the stronger alkalies, such as baryta, soda, and potash, without the presence of carbon. Phosphates are soluble in any silicate ; and if silex increases, so that no alkali is left with which the phosphoric acid can combine, the latter, unless carbon and a portion of the protoxide of iron in the cinder are present to reduce it, will evaporate, or form phosphuret of iron, which, of course, will then remain in combination with the iron. Where there is a large amount of phosphorus in pig iron, we require an equivalent amount of free alkali for its removal. The latter, in the course of the puddling process, which is an oxidizing process, will become a phosphate, even though its first compound was a phosphuret. As a phosphate, it cannot be of injury to the iron, if the latter is free from carbon or silicon. Therefore, the wish to exclude phosphorus containing ores is an unfounded prejudice. In the charcoal forge, iron containing phosphorus cannot be wrought to advantage. As fluxes, phosphates occupy a position between borates and chlorides ; they are not so much of a reducing agent as the former, nor so much of an oxidizing agent as the latter. Chlorides, such as common salt, are very powerful oxidizing agents, therefore, in the blast furnace, they are not in their legitimate place ; for to make gray iron, when a considerable amount of chlorine or a chloride is present, is impossible. But under certain conditions, chlorides are the best materials to improve iron in the refining process ; they are far superior to the strongest alkalies. They are more permanent than borates, phosphates, or sulphates. But, in the presence of carbon in excess, they

are very volatile. When in the condition of neutral compounds, they are but little inclined to associate with other salts; if the latter are well heated, they evaporate. Chlorides possess great power of dissolving alkalies in a heated condition; and before chlorine is moved by silex, it will drive off every other acid. The employment of common salt in the refining of iron, thus shown to be unquestionably useful, is of very limited application, owing to the difficulties involved in its use. Where carbon is present, chlorides are useless, for, in a given heat, they will evaporate without leaving a trace behind. Where the heat of a puddling furnace is quite high, as in the melting of some kinds of pig iron is necessary, any chloride introduced into it will immediately evaporate; and thus time is not afforded for its combination with the alkali of a cinder, even though an abundance of it is present. No element is so well adapted to improve iron as common salt. But, in consequence of imperfect knowledge, its application, thus far, has been extremely limited. In fact, because it has failed to produce certain results, which a knowledge of its nature and constitution ought to teach us we have no reason to expect, many ignorant persons have refused to employ it at all. In puddling, the furnace ought to be as cold as possible, if salt, or any chlorides, are applied. Therefore, iron which melts at a low heat is preferable; the chlorides must be very dry, and finely ground; and a large quantity of cinder is required to prevent, as far as possible, the immediate contact of the chlorides and iron, before the solution of the latter takes place. If chlorides are brought in direct contact with the iron, the chlorine and a portion of the iron will evaporate, and consequently, no benefit will result from the oxidizing nature of the cinder. A cinder containing chlorine is a powerful oxidizing agent. Neither silex, phosphorus, sulphur, manganese, nor iron can withstand its influence, even though it exists in small amount. It will oxidize phosphorus, sulphur, and carbon, and cause their destruction; and of these elements it aids to form acids, which are either combined with the alkali of the cinder, if any are free, or are ejected in the

form of sulphurous and phosphorous acids, and carbonic oxide. For these reasons, an excess of salt is very injurious, for it will evaporate, and oxidize a large portion of iron, and the iron which is produced will be dark and weak ; but by applying it in proper quantity, we shall obtain an iron which, in strength and color, cannot be surpassed.

The above are the only elements which are serviceable for the improvement of iron. But, as this statement may seem to require some explanation, we shall enter upon a brief consideration of those materials which might possibly be made to serve the desired purpose. We shall only enumerate oxidizing agents, for these alone at present interest us.

The sulphates are almost superior to chlorides as oxidizing agents ; but the danger of decomposition, by which sulphurets would be left in the iron, precludes their use. The decomposition of the acid would at once deprive the cinder of its oxidizing power, and the sulphuret left in the metal will remain in the bar iron, unless the cinder contains a great excess of alkali.

Black manganese gives off its oxygen too soon ; it does not serve a much better purpose than any alkali. It possesses greater strength than the protoxide of iron, but it is inferior to soda or potash. Iron refined under its influence is generally hard, fibrous, and strong.

Soda and potash are excellent alkalies ; but, when applied in such quantity as to remove sulphur or phosphorus, they are too fusible to make strong iron. In small quantities, they are serviceable where the iron is of good quality ; but in large quantities, they increase the fusibility of the cinder to such a degree that the iron cannot become strong and fibrous. Besides, so strong is the heat of a puddling furnace, that the greatest part even of the carbonates will evaporate before a combination of the alkali and the cinder is effected.

Oxide of lead is perfectly useless, because of the shortness of the time in which it loses its oxygen, but we have applied the basic chloride of lead with success. This chloride is obtained from a mixture of litharge and

common salt, in the proportion of four pounds of the former to one of the latter. The mixture is moistened with water, and left to stand for twenty-four hours. We were induced to make this experiment from having observed a metal which produced the most beautiful bar iron we had ever seen. The metal was white, of a reddish flesh-colored cast; it was smelted from an iron ore containing lead in admixture. The lead separated from the iron in the lower part of the crucible. This metal, white as any metal can possibly be, though with a reddish cast, melted as thin as any gray iron containing phosphorus. It kept liquid for an unusual length of time. From an inferior pig iron, we obtained, by the application of the chloride of lead, an excellent quality of iron, though not equal to the white metal smelted from the lead containing ores.

To the following material we wish to call special attention; not on account of its quality as a flux, but because of the facility with which it can be applied. Its chemical composition is remarkable; and we are therefore induced to reflect upon the primary condition of those materials designed for the improvement of iron in the puddling furnace. We refer to the magnetic oxide of iron. Experience has proved that hammer-slag, roll-scales, and finely-powdered magnetic oxide are the best means of promoting the process of puddling. They do not produce the best iron, nor the fastest work; still, it is unquestionable that they are the most available materials at our service. Black magnetic ore, hammer-slag, and roll-scales constitute the magnetic oxide of iron. This is a combination of one atom of protoxide and one atom of peroxide of iron, forming a neutral compound which is less easily decomposed than the peroxide, and which resists the influence of carbon for a shorter time than the protoxide. If such a compound is brought in contact with cinder, it will be neutral, because it melts only at a very high temperature; and, unless carbon or some other reducing agent is present, it will remain in the cinder in its original integrity; at least, it will resist decomposition for a great length of

time. At first, it stiffens the cinder. This is just what is required; for a strong cinder enables us to separate the iron properly; at least, this is the object which we always aim to realize. In the progress of the work, the uncombined particles of the magnetic oxide will come in contact with the melted iron. If the iron is of good quality, and carbon alone requires removal, the compound oxide will be decomposed by the carbon; carbonic oxide will escape with a blue flame on the surface of the cinder; and the protoxide which results will combine, should it come in contact with silex, or divide the silex of the cinder with the other alkalies. With respect to the removal of carbon, many other materials may be employed with even greater advantage; but with regard to silex this is not the case. Any alkali will remove silex from the iron, but for the removal of silicon, the black magnetic oxide is preferable to even the best alkalies. If silicon exists in the pig iron—in which case oxygen is required to form an acid—and the melted iron is brought in contact with the magnetic oxide, the peroxide of the compound is decomposed; oxygen is thus imparted to the silicon; the newly-formed silex and the newly-formed protoxide of iron will then combine instantly. A more perfect compound than the sesquioxide of iron can scarcely be imagined; still, in the progress of knowledge, some more advantageous method may yet be found for the removal of silicon. Sulphurets and phosphurets are decomposed with facility by the magnetic oxide; but the resulting sulphates and phosphates are, in turn, decomposed by carbon; and as no wrought iron is entirely free from carbon, the magnetic oxide is not the best material at our service for the removal of sulphur and phosphorus.

Great attention is therefore required so to arrange matters in the puddling furnace that we shall have a cinder slightly less fusible than the iron. With white metal, it should be less fusible for want of alkali; and with gray iron, by virtue of the absence of silex or acid. But in most cases, it is advantageous to have a somewhat alkaline cinder, because a better yield is produced.

After the iron is melted, and fluxes are applied, the cinder begins to thicken, long blue flames escape at the surface, and the whole mass begins to ferment. Blue flames appear only when the work goes on well; in which case carbonic oxide is formed below the cinder. If the cinder is too alkaline, that is, if it contains too much iron, no such flames appear; but a lively ebullition is visible on the surface of the cinder. The same result occurs, if we throw in oxygen in too large amount, or that which is too loosely fixed. The reason of this is the formation of carbonic acid, instead of carbonic oxide, below the cinder; and it requires very good metal indeed to make valuable iron by such manipulation. To produce blue flames, and to prevent the formation of carbonic acid, the most effective means we possess are a cold hearth at the commencement of the operation, diligent manipulation, and the application of the smallest quantity of fluxes that is commensurate with success.

After the iron has risen, and the mass has begun to ferment, the quality of the iron is fixed. Nothing but industry is now required, to obtain as large a yield as possible, and to make the iron work well at the squeezer. To an unphilosophical mind, the fermentation of the metal appears to be a singular phenomenon. In fact, few sights are more beautiful than that of a mass of iron from 700 to 1000 pounds weight, occupying at first scarcely the depth of an inch in the hearth of the furnace, gradually rising, fermenting, and boiling while small particles of iron, in apparently spontaneous motion, suddenly appear on the surface in small clusters like brilliant stars, and then as suddenly disappear. This fermentation happens only with metal that contains a given amount of carbon. White metal, which contains little or no carbon, does not ferment. Not only the amount of carbon, but the composition of cinder, influences fermentation. The cause of the boiling is nothing else than the evolution of gas, generated by the combination of oxygen and carbon. If the cinder which covers the liquid iron is very fusible, the gas escapes in bubbles on its surface, and the metal does not rise. If the cinder

possess a certain tenacity, if it is slimy like soap water, it will resist the escape of the gas, and rise until its surface is close to the flame of the furnace, when, becoming warmer and more liquid, its power of resistance is diminished. The slimy consistency of the cinder is produced by silex, but more perfectly by clay; the latter may be derived from the pig iron, or it can be charged with the fluxes. If we reflect upon this quality of clay, which is the same under all circumstances, we shall arrive at the cause of its beneficial influence upon iron. Our exertions are chiefly directed towards obtaining a well-defined cinder; neither too acid nor too alkaline. Clay fulfils these conditions. It serves both as an acid and as an alkali. It fluxes, and in the mean time will strengthen the body of the cinder. It is very serviceable in removing phosphorus, for with phosphoric acid it forms a fusible compound of great solvent power. Though experience were not in its favor, a consideration of its quality ought to convince us of its great utility in the puddling furnace. If the above explanation of the causes of fermentation is correct, it follows that the process depends upon the quality of the metal, and upon the nature of the cinder. Nevertheless, an experienced and skilful workman will make almost any metal boil, provided it contains but little carbon.

As the fermentation proceeds, the iron coagulates, that is, becomes granular below the cinder. As the small particles formed still contain a portion of carbon, which combines with oxygen derived from the cinder, the newly-formed carbonic oxide rises, and, in its ascent, draws along with it a small crystal of iron, which, coming to the surface, burns for a moment with a vivid light, and then disappears, because, after it loses its bubble of gas, there is nothing to counteract its gravity. This motion of the particles of the iron continues until the carbon of the metal is exhausted, or until the oxygen of the cinder is so diminished that no more gas can be formed; after which the cinder gradually contracts, and sinks to the bottom of the furnace, leaving the iron, to a greater or less degree, unprotected, and exposed to

the heat. Metal containing silex, silicon, phosphorus, sulphur, but no carbon, will not ferment, for no gas is liberated to cause fermentation. Therefore, such metal is greatly exposed to the heat and oxygen of the furnace, and works too quickly; hence the difficulty of improving it, even though it is very fusible. We thus see the advantage of fermentation in working inferior pig iron. As boiled iron is preferable for small iron rods, wire iron, blacksmiths' iron, and nails, we should always seek to obtain gray pig for the boiling process.

After the fermentation is finished, the oxidation of the iron commences; for, if the process has been properly conducted, all the previous operations will have tended only to remove impurities. The time at which this takes place depends upon the time occupied in finishing the heat, and upon the amount of silex the cinder contains. The oxidation of the iron serves to flux the slag, which becomes more and more liquid, as the temperature of the hearth increases. At this stage of the process, the utility of the iron boshes is evident, for, should the furnace have been lined with bricks or stones, all the alkalis we have applied, and all the iron which has been burnt, would have been wasted in their destruction. Besides, the main object of our skill and industry is to increase the amount of alkali in the cinder; but this object is directly counteracted by brick and stone boshes.

l. Having delineated, though by no means having exhausted, the various matters which relate to puddling, we shall take a critical view of the present mode of refining. We shall also investigate the cause of the improvement which results from the sudden cooling of metal, and shall conclude the chapter by a few general remarks on wrought iron.

The run-out fire, which is generally employed for refining iron, is based upon principles derived from the charcoal forge. Before hot blast was introduced into blast furnace operations, this was doubtless a useful apparatus. Pig metal which, fifteen years ago, would have been considered worthless for the forge, is now

employed in the manufacture of iron. The run-out fire labors under the same difficulties which exist in relation to the puddling furnace with iron boshes. For iron which contains carbon in small amount, or in chemical combination, its hearth is too cold. From gray charcoal pig iron, of good quality, the run-out produces a tolerably useful article. But we do not need it for this purpose. Cold blast gray pig may be worked to advantage in the puddling furnace without difficulty. Since the introduction of hot blast—that is, since the use of anthracite and stonecoal—quite a revolution has taken place in the chemical constitution of pig iron: the amount of chemically combined carbon has increased; silicon and other reduced matters are more generally present; and even the grayest specimens of metal are not free from unoxidized elements. To these causes, the difficulty of refining hot blast iron may be mainly attributed. Our previous investigations have proved that a high heat is required for the removal of silicon; but a still more necessary element is a cinder which does not too freely yield its oxygen. To what extent does the run-out fire fulfil these conditions? With respect to heat, it is but little better than the puddling furnace; and with respect to cinder, it answers scarcely a better purpose. Analysis has shown that the cinder of the run-out fire contains as much protoxide of iron as the cinder of a puddling furnace. A finery cinder from Dudley, England, contained siliceous matter 27.6, protoxide of iron 61.2, alumina 0.4, and phosphoric acid. If we smelt very impure pig iron in such a cinder, we cannot produce iron of good quality; this is especially the case should the iron have been smelted by hot blast. For the melting of such iron, we require a cinder containing less alkali. Less alkali is required to make good iron in puddling. From the amount of iron in this cinder, it is evident that the run-out fire cannot improve bad pig iron in any high degree, unless there is a serious loss in metal.

Since the introduction of coke, anthracite, poor ores, and hot blast, the iron business has undergone a change.

At the present time, we cannot avoid producing pig iron, which, a few years ago, would have been considered worthless. This metal it is now our object to bring to as high a standard as the best iron of the ancients. In the accomplishment of this object, it is evident that cautious manipulation and scientific knowledge are required.

The finery is considered a link between the blast furnace and the puddling furnace; that is, it is believed to occupy the same relative position between these furnaces that the blast furnace occupies between the ore and the finery. The blast furnace is an apparatus designed for the removal of impurities with the least possible loss of iron. It answers the purpose of its construction excellently. But what is the fact with respect to the finery? Simply this: the cinder from the finery contains more iron than that from the puddling furnace; and, when we consider that the contact of coke or anthracite increases the amount of silex in the former, we find that there is a far greater loss of metal in the run-out fire than would result from the same pig iron in the puddling furnace. If this is the only advantage derivable from the finery, it is surely far preferable to take the worst kind of pig iron directly to the puddling furnace.

m. The philosophy of the improvement of metal consists in the circumstance that a part of its impurities, which are originally in chemical combination, are converted into mechanical admixtures. Iron containing a small amount of carbon, silicon, or phosphorus is always more hard and strong than pure iron. Pure iron is quite soft. Impure iron assumes a crystalline structure on being suddenly cooled. The largeness of this structure is proportional to the amount of carbon the iron contains in chemical combination, and in proportion to other matter. Between the crystals, minute spaces are left, which serve for the absorption of oxygen. By this means, silicon and calcium may be oxidized; but such is not the case with carbon, phosphorus, and sulphur. Therefore, the metal improves in quality in proportion as oxygen finds access to its impurities. For this reason,

the habit of running metal, or any kind of pig iron designed for the forge, into iron chills, is a good one, and is worthy of imitation wherever it is applicable. By this means, the absence of sand and the cleanliness of the metal are secured. For the same reason, the metal is tempered; that is, the plates of metal, or, as in some parts of Austria, rosettes of metal, are piled up with small charcoal, braise, and exposed to a lower temperature than a cherry-red heat, for twenty-four or forty-eight hours, in a kind of large bake oven. By this method, the value of the metal is improved for the manufacture of soft and fibrous iron. It is not applicable to plates from which steel is to be made.

n. Wrought iron, if of good quality, is silvery white, and fibrous; carbon imparts to it a bluish, and often a gray color; sulphur a dark dead color without a tinge of blue; silicon, phosphorus, and carbon a bright color, which is the more beautiful the more the first two elements preponderate. The lustre of iron does not depend principally upon its color; for pure iron, though silvery white, reflects little light. A small quantity of carbon in chemical combination, phosphorus, or silicon increases the brilliancy of its lustre. Its lustre is diminished by siliceous matter, carbon in mechanical admixture, cinder, lime, sulphur, or magnesia. Good iron should appear fresh, somewhat reflexed in its fibres, and silky. A dead color indicates a weak iron, even though it is perfectly white. Dark, but very lustrous iron is always superior to that which has a bright color and feeble lustre. Coarse fibres indicate a strong, but, if the iron is dark, an inferior article, unfit for the merchant or blacksmith. But, where the iron is of a white, bright color, they indicate an article of superior quality for sheet iron and boiler-plate, though too soft for railroad iron. For the latter purpose, a coarse, fibrous, slightly bluish iron is required. Iron of short fibre is too pure; it is generally hot-short, and, when cold, not strong. This kind of iron is apt to result from the application of an excess of lime. Its weakness is the result of the absence of all impurities. The best quali-

ties of bar iron always contain a small amount of impurities. Steel ceases to be hard and strong if we deprive it of the small amount of silicon it contains, or if by repeated heating, that silicon is oxidized. This is the case with bar iron. If we deprive it of all foreign admixtures, it ceases to be strong, tenacious, and beautiful iron, and becomes a pale, soft metal, of feeble strength and lustre. Good bar or wrought iron is always fibrous; it loses its fibres neither by heat nor cold. Time may change its aggregate form, but its fibrous quality should always be considered the guarantee of its strength. Iron of good quality will bear cold hammering to any extent. A bar an inch square, which cannot be hammered down to a quarter of an inch on a cold anvil without showing any traces of splitting, is an inferior iron.]

o. In the above remarks it is plain that Mr. Overman does not coincide with Dr. Percy in the supposition of the latter that calcium and iron will not combine. The light which has been thrown upon the conditions of carbon in iron, in late days, would slightly modify some of the expressions in the foregoing pages; but the views in respect to pure iron have been corroborated in various ways in later years. In other respects the remarks are of great practical value.

Special Process of Blooming Pig Iron.

A modification of the bloomary process, as hitherto described, may be found at the Logan Iron Works, Bellefonte, Pa., which is extremely simple and direct, resulting in the forming, commercially speaking, of an almost absolutely pure iron. The furnace is a few inches above the general floor of the forge house, and the size about large enough to make one bloom of 200 or 225 pounds. It is about three by four feet, the long way running back from the workman. The instrument used for turning, lifting, and aggregating the iron, is called a fudgeon, and answers to the rabble of the ordinary puddling furnace. The waste heat passes up and through a chamber immediately over the forge hearth

where the pigs are placed, which become red hot before they are ready to be drawn down upon the bed of charcoal, previously prepared. The pigs thus drawn down upon the charcoal bed are covered and the blast turned on into both tuyeres right and left. After a few minutes the iron begins to melt; it is decarbonized by the blast, is worked into shape by the "furgeon," and then lifted up clear of the bed, and laid upon the top of the same bed again, some additional charcoal put around, and the blast turned on. The iron is now melted in what is called the "sinking" process, wherein the iron drops through the coal until entirely passed into the hearth; it is now cooled and again agglomerated into the ball or "loup" by the furgeon (pronounced furgun), the blast having been turned on fully previously; it is then lifted out a balled loup and carried to the hammer. The cinder is tapped off through a hole in the front iron plate, and is rich in iron and with so much silex that it easily emits sparks when the pen-knife blade is struck against it. Of course, this process is attended by a large loss of iron, while the loup, which gives rise to the cinder, is not thereby improved as in the puddling furnace. But in this particular instance the iron is singularly pure, and the blooms command \$85 per ton at the forge. One ton and a half of pig yield 2464 pounds of bloom. The charcoal furnace yielding the iron is nearly adjoining the bloomary. This furnace is only 32 feet high, about 26 inches across the tunnel-head opening, 8½ feet bosh, and the slag is allowed to flow out from the hearth whenever it rises above the forehearth. The breast is covered with a simple plate of iron; the cinder is always in sight; as soon as the iron appears, the crucible, or tapping hole is opened, and the iron is tapped off into iron moulds. There are three casts per twenty-four hours, two tons per cast, 150 bushels hard coal (18 pounds to the bushel) to the ton made. Charges: 700 to 750 pipe ore (brown hematite), 27 bushels charcoal, 80 pounds gray limestone of good quality, pressure ½ to ¾ pound per inch, nozzle 2½, two wooden blowing cylinders worked by water-wheel. Some finery cinders,

about 30 to 40 pounds, are added to the charges and said to improve the iron, which at present, May 26th, 1869, is all forge iron, and used at Stewart & Co.'s Wire factory, Easton, Pa., and reported as a very fine iron.

This bloomary process is interesting as an example of blooming from pig iron in a peculiar process.

CHAPTER IV.

FORGING AND ROLLING.

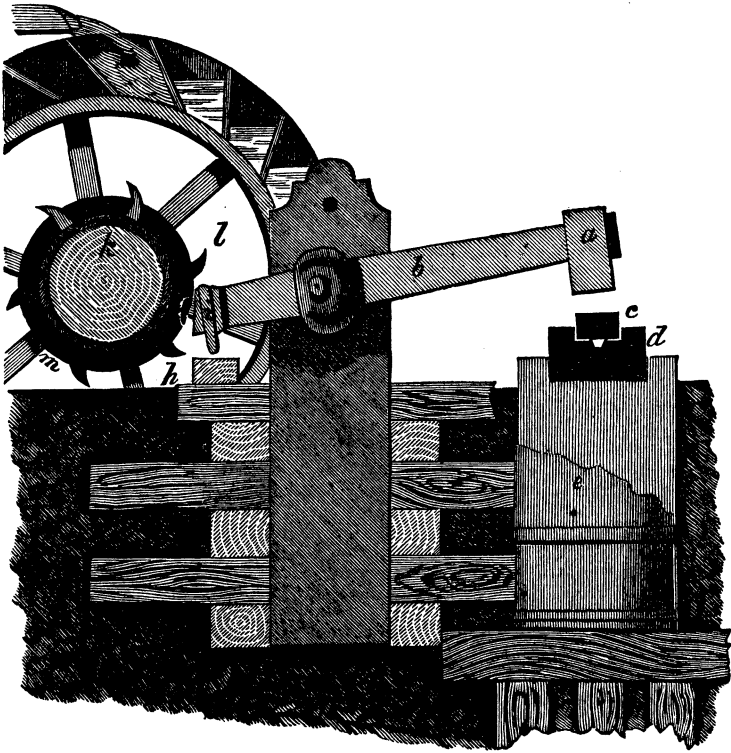
WE have thought it best to introduce any modern improvements in that department which forms the subject of this chapter by using the text of Mr. Overman's chapter upon this subject, emended by certain necessary alterations. To these remarks, which very properly introduce the whole subject, we shall add descriptions and further remarks upon late inventions and improvements.

Forge Hammers.

[a. The most simple machine by which iron is forged is the forge-hammer, often called the tilt-hammer. The leading principle which we seek to secure in its construction is solidity; and every variety of form has been invented simply to give permanency to the structure, which is mainly endangered by the action and reaction of the strokes. The common form of a forge-hammer with a wooden frame is represented in Fig. 173. a. The cast-iron hammer, which varies in weight, according to the purposes for which it is designed, from 50 to 400 pounds. For drawing small iron and nail rods, a hammer of the former size, is sufficiently heavy; but for forging blooms of from 60 to 100 pounds in weight, a hammer weighing 300 or 400 pounds is employed. Such a hammer is represented by Fig. 174, in detail. It

should be cast from the strongest gray iron, and secured by wooden hedges to the helve *b*. The fastening of the

Fig. 173.

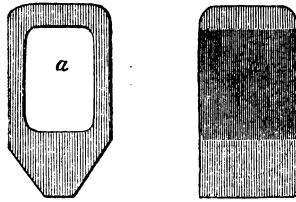


Tilt-hammer.

hammer to its helve is, in many cases, effected with difficulty, especially if the cast is weak; and to this weakness attention must be paid. If the hammer is of good cast iron, or, as in many instances, of wrought iron, there is no difficulty in wedging it. If wooden wedges are properly applied, and well tightened, long iron wedges may be driven in between them; but these must be so placed as not to injure the helve, or lie too close to the iron of the hammer. These iron wedges are then secured by a sledge, weighing thirty or forty pounds, with

a long handle. This is suspended on a rope, or, what is better, a small iron rod or chain, adjusted upon the head

Fig. 174.

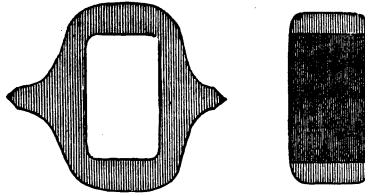


Hammer.

of the wedge, by which means a horizontal stroke is secured. The face of the hammer is polished, and in case long bar iron is to be drawn, it is frequently twisted with the helve. *c* The anvil, a cast-iron block, about the weight of the hammer; but it may be of less weight if the iron stock *d* is employed. *e* A log of wood from six to eight feet in length, and frequently four feet in diameter. This log is secured at its base and top by iron hoops. It rests upon timber laid across piles very stoutly driven in the ground. Such a foundation for the log, or hammer-stock, is requisite, because rock, or the most solid ground, forms at best but an insufficient base. The two standards—sometimes of wood, sometimes of iron—in which the hammer has its fulcrum, need no description; neither does the mode of fastening them. All that is required here is strength, no amount of which is superfluous. The helve *b* is of sound, dry hickory, or more commonly, of white oak. The fulcrum *g*, a cast iron ring, is represented by Fig. 175; this must be tightly wedged upon the helve. *i* A wrought-iron ring, fastened to the helve; on its upper side it receives the taps of the cams; on the lower side it strikes against a vibrating piece of timber for the purpose of increasing, by recoil, the force of the hammer. It is easily understood that if the hammer is thrown up with force, the reaction upon the fulcrum and framework must be immense. This is especially the case where a high stroke

of the hammer is required, as in forging blooms. The destructive power of this reaction increases with the

Fig. 175.



Helve-ring.

ratio of the weight, and according to the square of the speed. That is to say, if the hammer strikes with 100 pounds force against *h*, when seventy strokes per minute are made, it will, when 140 strokes per minute are made, strike with a force of 400 pounds. The same rule is applicable in relation to the space described by the hammer. If the hammer, lifted ten inches, strikes with a force of 1000 pounds, it will, when lifted twenty inches, strike with a force of 4000 pounds. This shows the great increase of power which follows that of speed, and imparts some idea of the reaction which machinery of this kind sustains. If the length of the shorter part of the helve, from *i* to *g*, is very small proportionately to that of the longer part, the reaction of course increases, in a high degree, upon the vibrating beam. This latter circumstance, and the reaction upon the fulcrum, made it necessary that the recoil should be brought more upon the hammer itself. In the attempt to effect this result, a great variety of forms of the hammer was produced. The shaft *k* is commonly made of wood. If the motive power is water, the waterwheel is directly fastened upon it; if it is steam, a flywheel is attached, and the power applied by leather straps or belts. The cast-iron wheel *m*, which is often of an octagonal form, but generally round, must be strong; in it the cams *l* are fastened.

These hammers are troublesome implements. For shingling blooms, they can be replaced by squeezers; but they are required for drawing bar iron, and making

pattern iron, such as sledge moulds. The steam hammer is a fine implement, and is well adapted for forging steam-engine shafts: but the smaller kind of these steam hammers work so slowly that they do not answer for drawing iron; at least, they make but eighty or 100 strokes per minute; while it is necessary that a hammer suitable for drawing iron should make at least 150 strokes, and smaller hammers from 150 to 300, and even 400 strokes per minute. The hammer should be an independent machine, with an independent power. It cannot be connected with other machinery, for the speed of the hammer should be perfectly under the control of the hammerman, who should be enabled to make twenty, or 400 strokes, at pleasure. Steam is the cheapest motive power in iron works, because surplus heat for its generation is always available.

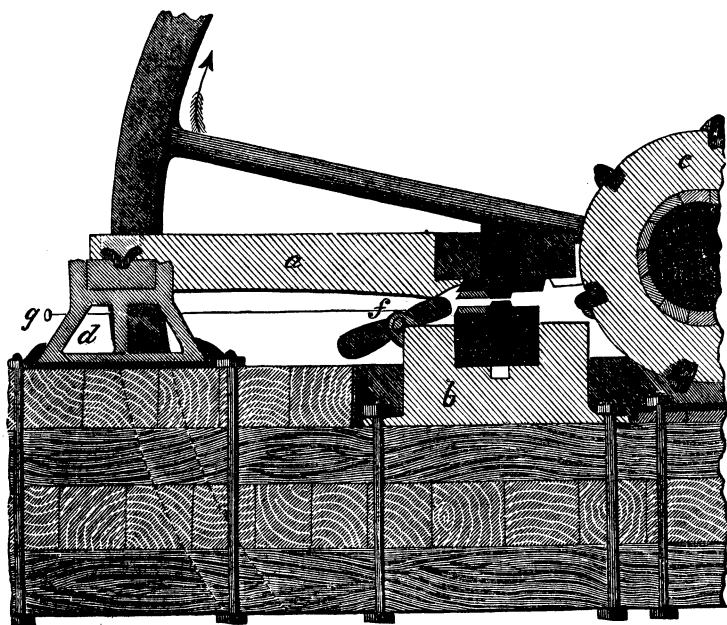
b. For the shingling of blooms, and slabs for boiler-plate and sheet iron, the iron T hammer is generally employed. Fig. 176 represents a side view, and in some parts a section of the hammer, flywheel shaft, and the stock of the anvil. The whole machinery is constructed of cast iron, with the exception of the foundation below ground, which is built of timber. The weight of the whole amounts to more than from thirty to forty tons. The hammer *a* generally weighs from four to five, the anvil stock *b* from five to eight, and the cam ring *c* from three to four, tons. This machine is now superseded by better machinery; and as no one, at present, thinks of erecting a new T hammer, a full description of it is unnecessary.

c. A hammer designed for the same purpose as the above T hammer, and quite as heavily and clumsily constructed, is used in some parts of Europe, though not, to our knowledge, in the United States. In this machine, the power is applied between the anvil and the standards.

d. As many T hammers are yet in use, and will doubtless remain in use for the shingling of slabs, it will probably be of advantage to mention an ingenious jack. With the common jack, the catching is difficult,

if the resting-place is worn out, or if an inexperienced workman takes hold of it; so much so, indeed, that the

Fig. 176.



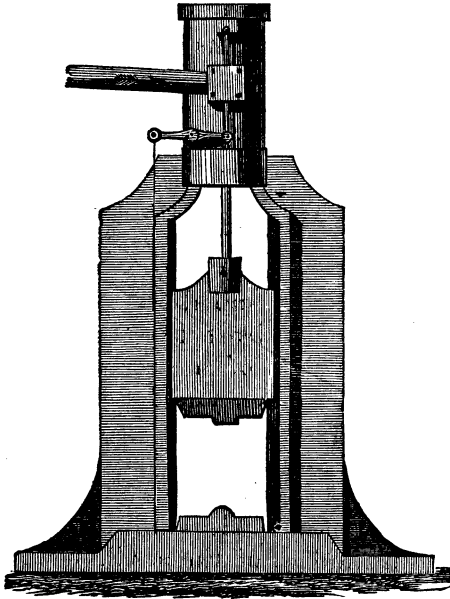
Large forge hammer—T hammer.

life and limbs of those around the hammer are in danger. In the illustration, a lever, *f*, made of wrought iron, is represented; this turns round a pin placed near it, and rests on the avil stock. *g* is a handle to a small iron rod, fastened to the lever *f*. By moving this lever, a small boy sitting at *g*, and protected from the sparks by a board, has it in his power to arrest the hammer at any moment without difficulty. This simple machine is infallible, and deserves to be employed. Besides, it is cheaper than the old jack.

e. The steam hammer before mentioned, is a highly useful machine for shingling blooms or slabs, in an establishment where a heavy hammer is necessary. Fig. 177 is a representation of the general form of the machine.

f. The shingling of bloom from balls is generally performed by welding a rod of about an inch square, pre-

Fig. 177.



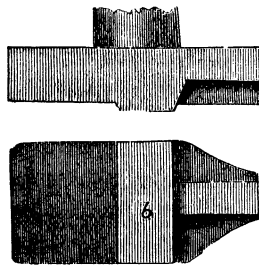
Steam hammer.

viously heated, to the ball. This rod serves as a handle to move the bloom under the hammer, and, when the bloom passes the rollers, as is the case in puddling forges, or when it is to be sent to another place, it is cut off. In the charcoal forge, such bars are to be welded to every small lump of iron designed to be drawn into any specific form. In puddling establishments, these bars are troublesome, and occasion loss of iron, such as that wasted in heating the bars; this heating is generally done in the fire grate of the puddling furnace, and not unfrequently in the back of the flue. In well-conducted establishments, this iron is rolled directly from the blooms in the roughing rollers, in which a couple of grooves are expressly made for that purpose. The puddlers are required to make their own rods. The

disadvantages connected with this system gave rise to many attempts to shingle with tongs; but these were attended with little success at the T hammer. At the steam hammer, tongs may be used without difficulty; the hammer is perfectly in the power of the hammerman. At the T hammer, this is the main difficulty to be overcome.

g. The faces of hammers and anvils are of various shapes; but the principle on which they are constructed is, that they should be more or less broad, according to the width of the hammer. Too small a face cuts the iron too much, and a very broad face works too slowly. In small hammers the face varies from one and a half to four inches in width; and the face of the T or steam hammer should be at least five inches broad. The anvil and hammer face of a steam or T hammer is almost a square plate, twenty inches in length, and sixteen in width. For shingling this would be too large; therefore, a face an inch in height is raised in the middle of the plate, and runs across the plate in a direction opposite to the workman. In addition to this, a second face is raised on the half of the anvil, running at right angles to the first. This serves for stretching or drawing. Fig. 178 shows the arrangement for shingling

Fig. 178.



Hammer faces to a T hammer.

blooms. The cross face *b* is generally extended to both sides when the machine iron is forged.] The upper cut shows the side view corresponding to the lower cut,

which is that of a plan; the projection seen in the upper view is the iron base which runs into the anvil block.

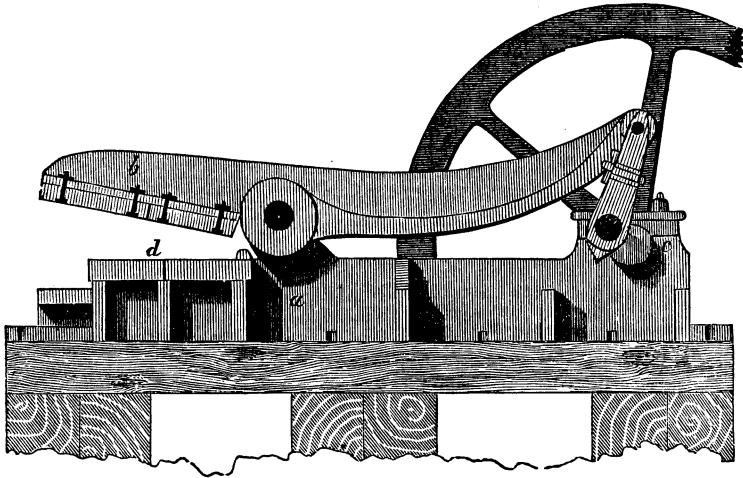
[Many manufacturers prefer hammers to other means of forging iron. Experience does not establish the wisdom of this preference. Good iron is good everywhere, and under all circumstances; and the hammer does not make it better. Nevertheless, the hammer has one advantage. Inferior workmen dread it, because it breaks badly worked iron more readily than any other machine. In the charcoal forge, it smashes raw iron; and in the puddling works it crumbles those balls which have been carelessly put together. Honest workmen, who do their duty, and work their iron well, are not afraid of it; nor is their iron, compressed by any method, inferior to that shingled by the hammer.

Squeezers.

a. Squeezers, or machines which condense a ball by pressure, have been employed, and, in most instances, have fulfilled the design of their construction. From experiments made, it is evident that good squeezers work as well as the best hammers. No difference in the quality of the iron subjected to the action of either is perceptible. In preference to other forms, we present a drawing of a lever squeezer, which is of simple construction. Fig. 179 exhibits it in vertical section. This machine is cheap and durable, and will squeeze 100 tons of iron per week. The illustration so clearly represents the whole machine, that a specific description of it is unnecessary. The bed plate *a* is cast in one piece; it is six feet long, fifteen inches wide, and twelve inches high. The whole is screwed down on a solid foundation of stone, brick, or timber; the first is preferable. *b* is the movable part, which makes from eighty to ninety motions per minute. The motion is imparted by the crank *c*, which in turn is driven by means of a strap and pulley by the elementary power. The diameter of the fly-wheel is from three to four feet. The anvil *d* is about two feet in length, and from twelve to

fourteen inches in width ; it is a movable plate, at least three inches thick, which, if injured, can be exchanged

Fig. 179.



Squeezer.

for another. The face of the working part of the lever exactly fits the anvil, and consists of plates attached by means of screws. It is desirable to have all these face plates in small parts of eight or ten inches in width. By this means they are secured against breaking by expansion and contraction. The whole machine including the crank and everything, is made of cast iron, and will weigh four or five tons.

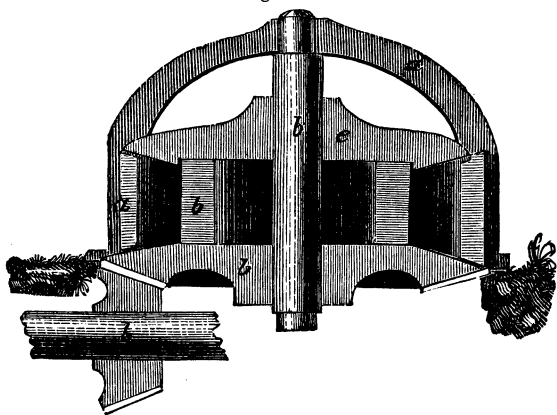
For the compression of puddled balls, these squeezers are, as we have stated, quite as serviceable as the best T hammer, or any other hammer. But for the reduction of charcoal iron, they have either not been tried, or they are insufficient. If the former, we would advise the experiment, confident that no difficulty will occur, provided the machine is sufficiently strong to resist the reaction of the hard and cold bloom. Charcoal iron is generally harder than puddled iron, and a stronger machine, therefore, is required to compress it. Still, there is no doubt that the squeezer will answer excellently, so far as the shingling of blooms is concerned.

Whether it is applicable to the drawing of bars is a question which experiment alone can decide. Should its adaptation be proved, and should the squeezer supplant the hammers of the charcoal forge, we believe that it would be the most useful improvement which could be added to the machines for forging iron. The imperfection of the lever squeezer is its liability to wear out at the fulcrum, and in the brass boxes of the crank shaft and connecting rod. The motion of the outer points of the working part seldom extends beyond four inches, and frequently less. If a separate place for upsetting* the blooms is made at the face, but little stroke is needed; but if no such offset is appended, a higher lift is necessary.

b. One of the most useful machines—labor-saving machines—with which we are acquainted, is Burden's rotary squeezer. This is an American invention. It includes the fundamental, distinctive element of a perfect machine, that is, rotary motion. Experience has proved this to be a highly useful squeezer, and it is now in a fair way of supplanting all those machines by which puddled balls are condensed into blooms. Many of the Eastern manufacturers employ it, and at the Western mills it appears to be quite a favorite. Fig. 180 exhibits it in vertical, and Fig. 181 in horizontal, section. The whole apparatus is of cast iron, and very strong and heavy, which, as a matter of course, is indispensable. Our illustrations are designed simply to convey a general idea of the machine. The stationary part of the apparatus is marked *a, a, a*; this consists chiefly of a cast-iron cloak, which incloses the movable parts, *b, b, b*. An eccentric space between the two main parts is thus left, in which the ball is formed into a bloom. The ball is inserted at *c*, moves round, and appears at *d*, a well-formed bloom. A few seconds are sufficient to accomplish this condensation. When the machine first appeared, a doubt was entertained whether it could duly accomplish the upsetting, that is, squeeze the bloom.

* Signifies squeezing at the end of a bloom, or roll of iron.

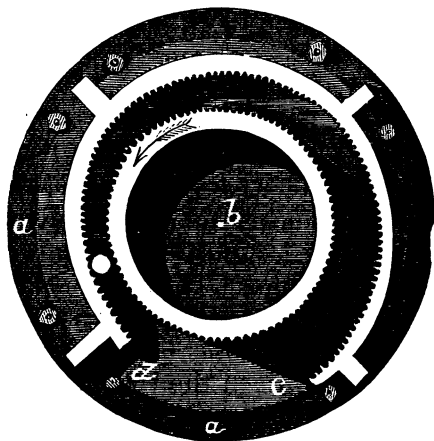
Fig. 180.



Rotary squeezer.

lengthwise; but no difficulty appears to exist where the balls are, as nearly as possible of equal size. Besides,

Fig. 181.



Ground-plan of the rotary squeezer.

the top *e* is movable, sliding up and down; but this motion is very slight.

At the double puddling furnace, this squeezer at once enables us to overcome a serious difficulty, namely, the loss of time and iron occasioned by the slower work of

the T hammer and the lever squeezer. If the roughing rollers are in such condition as to draw as fast as the squeezer forms blooms, a few minutes are sufficient to work off a heat of 800 pounds. This is one great advantage. The other advantages are that two workmen less are needed, and a great deal of repair and frequent disturbances obviated. In the working of the iron, hammers are unnecessary, because they do not improve it directly. Well-worked iron, put directly into the rough rollers, without shingling, is not in the least degree inferior to that shingled by the T hammer. Hammers are but imperfect machines; the remains of an elementary knowledge of engineering; and the sooner they are superseded by better implements of workmanship, the better.

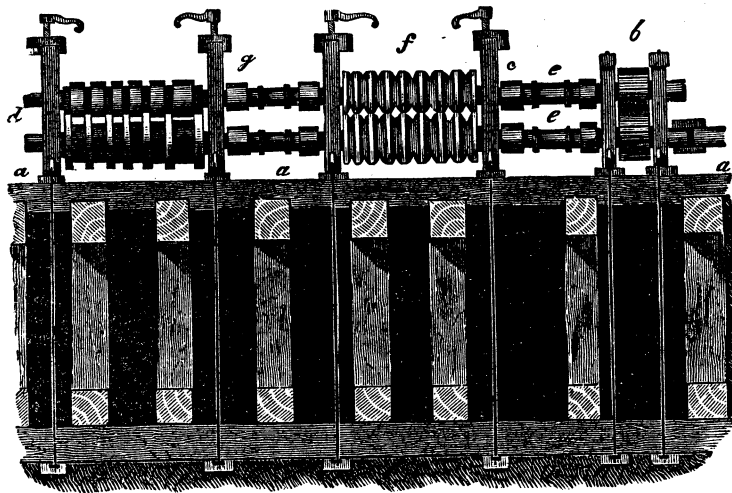
Roughing Rollers.

The shingled blooms are conveyed directly from the squeezer or hammer to the rollers, commonly called rough rollers. In some parts of Europe, no hammers or squeezers are employed; but the balls are taken directly from the puddling furnace to the rollers, which have large grooves, and in the first and second groove projecting ribs, for catching. We do not find any difference in the quality of the iron, whether shingled or put through the rollers directly from the furnaces, except that arising from the inability of the latter to effect the compression of the bloom lengthwise; this causes a waste of iron in the reheating furnace, because the rough bars are never so sound at the edges and the ends as those made from shingled or squeezed blooms. For this reason, it is preferable to shingle the balls, or to form sound blooms by some method before the iron is taken to the rollers.

The limited size of the engraving does not permit us to give such detailed views of the machinery as we would desire to give; still, we shall endeavor to make the subject as clear and comprehensible as possible. Fig. 182 shows a side view of a roughing train. Any

row, or more than one set of rollers, is called a train. The upper part above the sill *a*, is all made of cast iron. The part below *a* is the foundation below ground, and is here assumed to be a framework of timber. In most

Fig. 182.



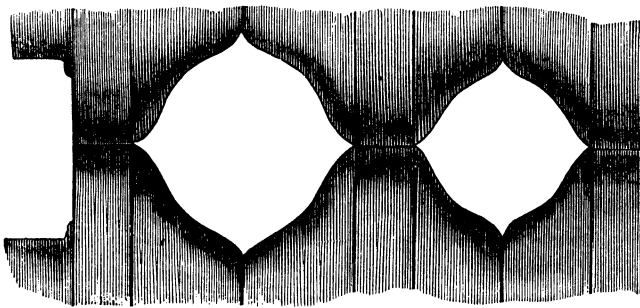
Roughing rollers, and foundation of timber.

of our rolling mills, the foundation of a train is made of timber, and answers well enough for a temporary purpose. Timber lasts but a short time. Good substantial works ought to have stone or brick foundations; these are not only more durable, but preserve the machinery by their greater stability: the machinery works more quietly, and does not make so much noise as when built upon a wooden frame. At *b* are two standards, carrying two cogwheels. These wheels are nearest to the steam-engine and the flywheel. They have the diameter of the rollers, in the dividing line, and serve to conduct the motion from the moving power to the rollers, giving the top rollers a motion independent of the bottom rollers. They are sometimes put close to the first set of rollers, forming, at the same time, the coupling boxes *c*; or they are fastened to the rollers at *d*, and conduct the motion back. Such arrangements are very imper-

fect; the first is troublesome, because the wheels do not stick to the rollers—the expansion and contraction caused by the heat of the rollers unfasten all filling between the wheel and the roller, or, if too close fitted, break the wheel. Fastening the wheel at *d* is equally bad, for then the coupling boxes between the top rollers break so frequently as to cause disturbance. The motion from the wheels *b* is conducted, by means of the coupling rods *e e*, to the rollers *f*; *e e* are cast-iron spindles two or two and a half feet in length, joined to the rollers by the coupling boxes *c*. The coupling boxes *g* are frequently cast in one piece with the rod, to make it stronger. *f* exhibits the roughing rollers; these take the bloom, and draw or reduce it into billets of greater or less size, according to the size of the flat bars intended to be drawn. For the making of hoops, nail-rods, and fancy rods less than half an inch square, the billets are reduced to an inch or an inch and a half square, and taken to the reheating furnace, to be directly converted into merchant iron.

a. Billets from the roughing rollers have to serve for square, round, and flat iron; in fact, the condensation and drawing of the iron are principally effected by the roughing rollers. For this reason, the grooves are not

Fig. 183.



Grooves in roughing rollers.

square, but their form is that of a section between a circle and a square. This form is shown by Fig. 183.

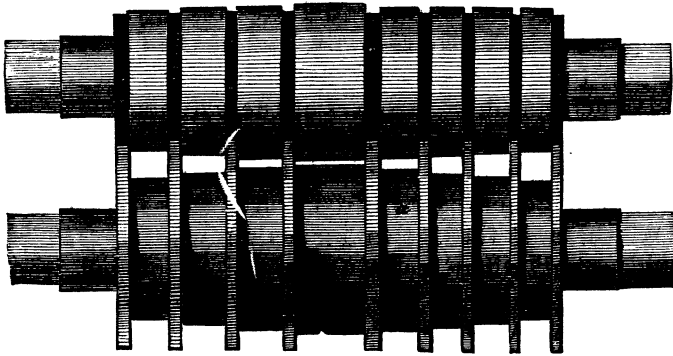
The grooves are a little shorter in the vertical than in the horizontal direction ; that is, the vertical is shorter than the horizontal diagonal. The hot iron, in being worked through these rollers, is turned one quarter at each groove, which secures sound edges in the billets. The bloom, in this first operation, is never so reduced as to become less than an inch or an inch and a quarter billet. The first groove, which receives the bloom, is to be sufficiently large to catch, for which purpose six inches are in most cases a good size ; at least, a larger size is seldom required for forge and puddled blooms. The degree of condensation, in these rollers, from one groove to the other (the decrement), is in the proportion of the squares of eleven to fifteen, or nearly one-half ; that is to say, the original length of the bar is nearly doubled in each groove. To reduce a bar from six inches to one inch square, we require seven grooves, measuring respectively 6, $4\frac{2}{5}$, $3\frac{1}{5}$, $2\frac{2}{5}$ inches, and $1\frac{4}{5}$, $1\frac{2}{5}$, 1 inch ; a roller forty inches long will thus be needed, if one inch between each groove is left. This proportion of decrement answers well for soft and puddled iron, and good, strong rollers ; but for hard and sound puddled iron, it condenses too rapidly. Charcoal iron it will work with difficulty. In these cases, it is advantageous to condense less and take more grooves. Fifteen to twelve is a good proportion ; condensation less than that is seldom required. For this purposes, nine grooves—measuring respectively 6, $4\frac{4}{5}$, $3\frac{2}{5}$, 3, $2\frac{2}{5}$ inches, and $1\frac{9}{10}$, $1\frac{1}{2}$, $1\frac{1}{5}$, 1 inch, requiring a roller forty-six inches long—are needed. Roughing rollers, if made of good strong cast iron, can be seven feet long ; the remaining three feet ten inches may serve for flat grooves. But for castings from anthracite or coke iron, it is not advantageous to use rollers of such length. Where the first cost is no object, it is advisable to make two sets of rollers for roughing ; to take one set for billets, the other for flat bars. In large and well-organized establishments, this plan is generally pursued ; it has the advantage that, should any accident happen, which is mostly with the flat rollers, the works

need not necessarily be stopped, for it very seldom happens that anything goes wrong at the billet rollers.

b. Where two sets of roughing rollers are used, the second set, see Fig. 182, is generally as long as the first, and coupled by spindles and boxes to the first. These rollers have flat grooves only, and make flat bars from one-half to three-quarters of an inch thick, and from two to six inches wide. Grooves of these dimensions cannot be cut into one pair of rollers: and, if a variety of width in the rough bars is required, two or more sets of flat rollers are generally required. Rough bars six inches in width, and those two inches in width, are seldom needed; but where certain dimensions of rod iron of greater or less width are constantly made, such as railroad iron or hoops, rough bars are of advantage. But this is of little consequence, and rough bars $3\frac{1}{2}$, 4, or $4\frac{1}{2}$ inches wide, and from $\frac{1}{2}$, $\frac{5}{8}$, to $\frac{3}{4}$ of an inch thick, are most commonly used. The first groove which receives the square bloom is the narrowest and highest; as the grooves diminish in height, they increase in width. The last would not be actually needed, were it not for the catching of the bar by the rollers; but it is advisable to make it as small as possible. The edges of a flat bar become less sound and fibrous, if the breadth of the grooves increases too fast. For the better comprehension of the subject, we will furnish a practical illustration, and annex a set of rollers, forty-six inches long, with grooves for bars four inches wide. The thickness can be altered by screwing the top roller upward or downward. Fig. 184 represents a set of rollers, which, if of good cast metal, are fourteen inches in diameter, that is, from centre to centre, which, of course, in this case, makes the bottom roller very strong. In the billet rollers, both diameters are the same. The first groove, marked *a*, is the finishing groove; therefore, it is four inches wide, and three-fourths of an inch thick. If now we increase in the ratio of from 12^2 to 15^2 , which is nearly 2: 3, the next groove is to be $1\frac{1}{8}$ inch, or a little less, high, and at least $\frac{1}{12}$ th, better $\frac{1}{8}$ th, of an inch narrower. The next groove will be $1\frac{5}{8}$ by $3\frac{1}{4}$; then $2\frac{1}{2}$ by $3\frac{5}{8}$; then

$3\frac{1}{2}$ by $3\frac{1}{2}$. The last groove is unnecessary, for it is a square, and will not take a billet of larger size than $3\frac{1}{2}$

Fig. 184.



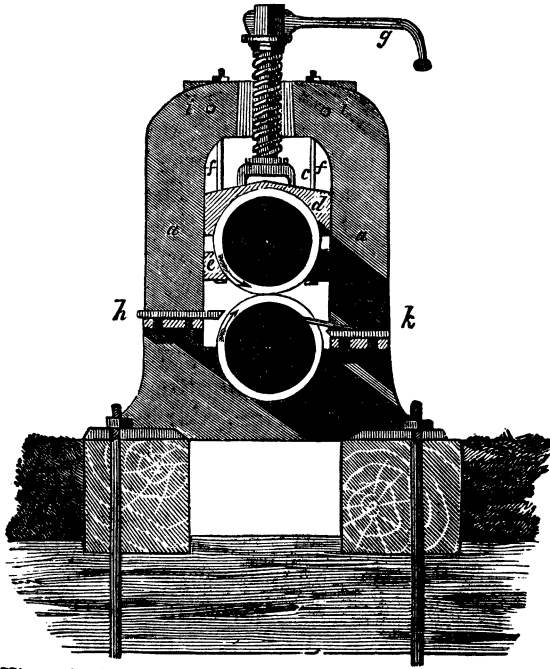
Flat rollers.

inches. Here we have four grooves, which, if we leave $1\frac{1}{2}$ inch collar between them, and two inches for the end collar, will take $2 + 4 + 1\frac{1}{2} + 3\frac{7}{8} + 1\frac{1}{2} + 3\frac{3}{4} + 1\frac{1}{2} + 3\frac{5}{8} + 1\frac{1}{2} = 23\frac{1}{4}$ inches. This is not more than half the length of the roller; and the other half may be arranged for a wider or a narrower bar. The bottom or ground of the grooves in the bottom roller is not quite square; the corners in both sides are left standing; instead of cutting the collar square down to the ground of the groove, it is somewhat slanted, and a quarter of an inch in the corner is left remaining. These round corners in the bottom roller squeeze the corners of the rough bars, whereby they become more sound, and diminish, in consequence, the waste of iron in the reheating furnace. Rough rollers generally make from thirty to forty revolutions per minute; this motion is sufficient where single furnaces and T hammers are in use, but it is too slow for double furnaces and rotary squeezers.

c. Fig. 185 shows a vertical section through the rollers and foundation, and a view of the housing frames, in which the rollers are supported. The housing *a* is a heavy frame of cast iron, being frequently ten by twelve inches square in the pillars, if designed for heavy bar

or sheet iron. For merchant bar eight by ten, for small bar six by eight, and for wire five by six inches is suffi-

Fig. 185.

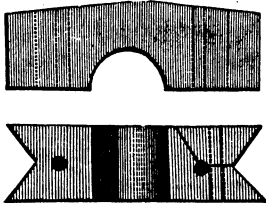


View of a housing, and section of rollers and foundation.

ciently strong, even though the metal is not of the very best quality. The width between the two pillars must correspond to the diameter of the rollers. Short rollers of good metal are, when of fifteen or sixteen inches in diameter, sufficiently strong; but long rollers, or rollers of weak metal, must be at least seventeen or eighteen inches. If the roughing rollers are eighteen inches in diameter, then the lowermost of the flat rollers will be at least three inches larger, which will bring the housings to twenty-two inches; adding one inch space, twenty-three inches will be the distance between the uprights. In common cases, five feet are a sufficient height for housings, and for railroad iron or sheet iron alone are a few inches more required. The wrought

iron screw *b* is generally four and a half inches in diameter, and moves in a brass box, which is hexagonal and a little tapered, so as to fit very tight into the cast-iron top. The thread of the screw is a square from one-fourth to three-eighths of an inch in size, so that one revolution of the screw amounts to one-half or three-fourths of an inch. The screw presses upon the cast-iron safety-cap *c*, which is calculated to break before any other part of the machinery; and the rollers, housings, &c., are thus secured against accidents. The cap *d* is of cast iron, lined with brass boxes, and these brass boxes are frequently lined with hard lead or type metal. This cap, as well as its bottom part *e*, slides on both sides in the housing, either in triangular or square grooves. Housings for roughing rollers are frequently found to be of a simple construction, and the sliding motion of the boxes is guided by a triangular prism, which gives

Fig. 186.



Triangular prism and cap.

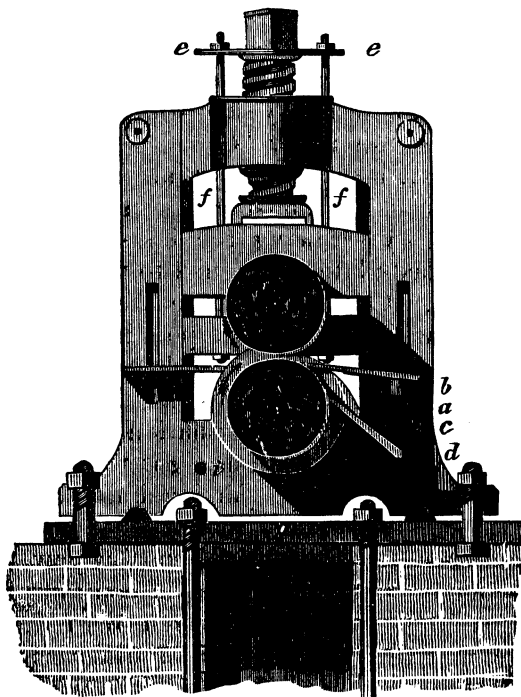
to the cap, the form shown in Fig. 186; this however is not the very best, and does not work well enough for square and round merchant bar. The two screws, *f, f*, Fig. 185, regulate the height of the top roller by means of the plummet block *e*. These screw-bolts pass through the cap *d*. The wrench *g* serves

to lower and raise the top roller, so as to increase or diminish the space between the two rollers. *h* is a cast-iron plate, called an apron, on the side where the hot iron enters the rollers; it is simply a plate filling the space between the housings, and joining the bottom roller, so as to form a bench on which the iron may rest. On the opposite side, *k*, is a similar apron, if roughing rollers; it is somewhat lower than the other, and its inner edge fits into the triangular grooves of the bottom roller, so as to scrape off any pieces of iron which fall loose from the bloom, or which stick to the roller. The fitting of this apron to the roller is somewhat difficult, and it is a preferable plan, instead of casting the scra-

pers to the plate, to form a straight edge, the apron somewhat smaller, and screw the scrapers to the plate, which then may be made of wrought iron. The screw bolts *i, i*, serve to steady the housings, and secure the close fitting of the boxes to the rollers.

If flat bar rollers, railroad, or fancy iron rollers are in the housings, a different arrangement with respect to scrapers must be followed. Fig. 187 shows a section of

Fig. 187.



Section of rollers and foundations.

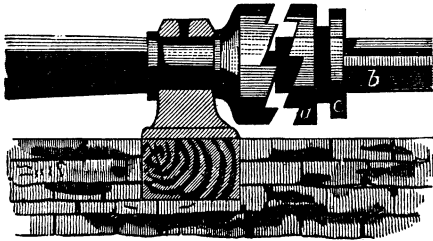
a set of flat bar or rail-rollers. Instead of the apron, there is only a square bar of wrought or cast iron, upon which wrought-iron scrapers, *b*, having the form of wedges, rest. These wedges are of the size of the grooves in the roller, and fit loosely into the grooves with their edges. Besides the scrapers, there is a second set below, *b*, called

guards. These guards, marked *e*, are wrought-iron wedges, resting in a strong cast-iron grooved bar *d*. In this drawing we see a different arrangement, with respect to the screw bolts *f f*, from that shown in Fig. 185. The nuts of the screws, instead of resting on the top of the housings, rest on a plate of wrought iron *e e*, which plate is fitted upon a round collar and the neck of the screw, and follows the screw in its upward and downward motion. This plan is preferable to any other, for it keeps the top roller always closely fitted in the plummer blocks, whereas, by the method shown in Fig. 185, the top roller is loose, and frequently liable to break. The arrangement here exhibited is well adapted for flat bar, rail, and heavy sheet-iron rollers, or in all cases where the top roller is moved by pinions. We find, in Fig. 187, also a different arrangement with respect to fastening the housings upon the foundation; this is effected by screwing the housings to the bed-plate *g*, which bed-plate is fastened to the foundation by separate screws. On the bed-plate are two projecting, prismatic ribs, which fit in corresponding notches in the housings. By these means the latter are kept in a straight line, and there is no difficulty in keeping a train in good order. The foundation is assumed to be of stones or brick, at least from eight to nine feet deep. In our illustration this proportional depth is not exhibited.

d. The connection between the motive power and the rollers is effected simply by a strong coupling box, that is, if the train is always connected with the engine; but if the motive power serves for different trains, or different machinery, another connection, which permits the stopping of the train, is to be made use of. Such a joint or cam box is represented by Fig. 188; the part *a* is a box movable upon the junction shaft *b*, by means of an iron fork resting on the collar *c*, or a simple lever bar, playing in the groove. The form or section of the junction shaft *b* and junction shafts generally varies. Some manufacturers employ simply square rods, others round. This is an object of some importance; because, if the junction

shafts are not of the right form or strength, the rollers are very soon made useless; the junction is so far injured as to break the coupling boxes, and occasion other accidents.

Fig. 188.



Cam box, coupling box.

A simply square section of the junction is not the best form. Experience has determined that the cross section, represented by Fig. 189, is, of all others, the most practical. The coupling boxes, on the junction shafts, between the rollers, are kept in their places by four wooden sticks; these, filling the four corners of the shaft, are kept together by leather straps, as represented in Fig. 190.

Fig. 189.



Section of a junction shaft, wood-filling and leather strap.

Fig. 190.



Junction shaft and coupling boxes.

The strength of these junction shafts varies according to the size of the rollers to which they are to be applied. We find them from ten to twelve inches in diameter for sheet-iron rollers, in which cases hard rollers with polished surfaces are at work; from eight to ten inches for common sheet-iron and railroad iron rollers; five to six inches for merchant iron rollers; and from three to four inches for wire and small rod. The quality or strength of the metal from which rollers, boxes and shafts are cast,

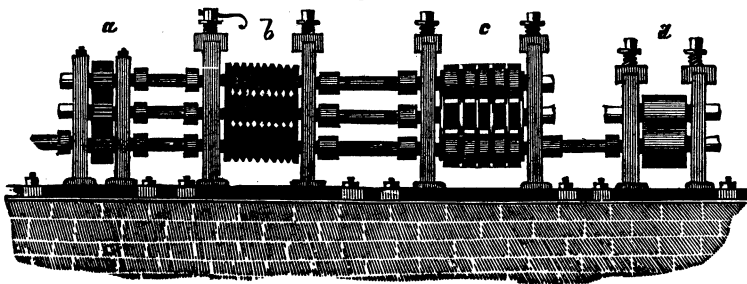
must of course determine the dimensions of the junction shafts.

e. Doubts have been expressed as to the propriety of working several trains of rollers by one flywheel. But nevertheless one flywheel is commonly employed, namely, the flywheel belonging to the steam-engine, which is generally somewhat heavier than the ordinary flywheel. This plan works well. Some of the Eastern works employ a flywheel at each train, but with what advantage we cannot see. This much is certain, that several flywheels attached to the same power, and moving in opposite directions, cause more breakage than one flywheel will cause. There is no necessity whatever for more than one flywheel, where there is but one engine, and the excuse for employing such is only to be found in a deficiency of power, which, in iron works, is one of the greatest faults that can be committed. We shall speak of this subject hereafter.

Merchant Rolling Mill.

a. For the making of wire, or small bar iron less than one inch square, or round, small hoops less than two inches wide, three rollers, one over the other, forming a set, and generally three sets a train, are required. Fig. 191 shows a section of such a train through a brick

Fig. 191.

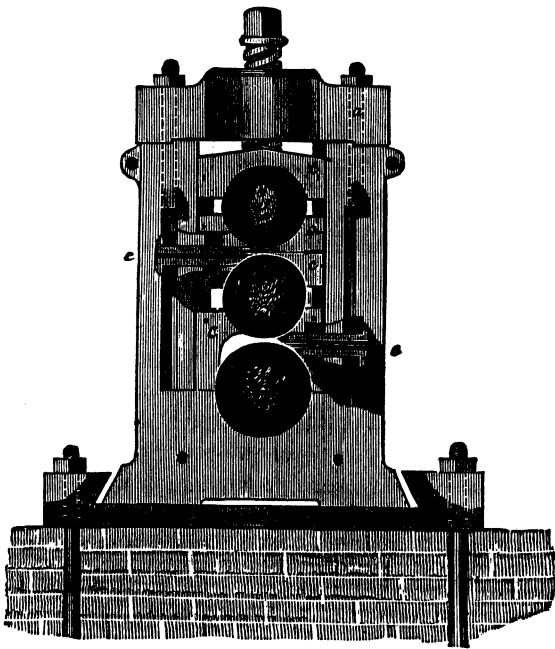


Merchant rollers for small iron.

foundation and a view of the rollers. *a* shows the union standards and pinions, of which there are three; the

power is connected with the lower wheel: *b* the roughing rollers, *c* the merchant rollers, and *d* hard rollers. The rollers *b* are never changed, and contain such grooves as will take the heaviest pack or pile necessary for small iron, which is seldom more than forty or fifty pounds. Rough bars three and a half inches wide, and twelve inches long, forming a square pile, will make such pack. The first groove must be three inches square, which makes a roller of ten inches in diameter necessary. Commonly, rollers but eight or nine inches wide are used for this train, in which of course, nothing heavier than one inch bars can be made; the first groove then measures two or two and a half inches, for which reason small rough bars, or billets, are required. The length of the rollers is seldom more than three feet, even

Fig. 192.

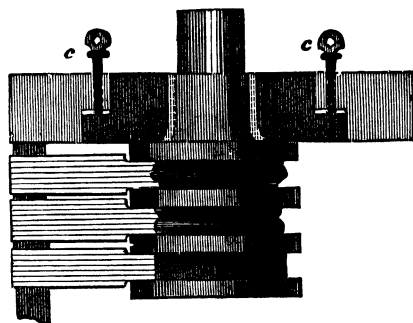


Section of merchant rollers.

if they are of large diameter; in the present case, it is of no use to have long rollers. The merchant rollers *c*

are arranged either for square, round, or flat bars. A construction of the housings is shown in Fig. 192, in which the necessary screws for adjusting the rollers may be seen. As the pressure from the rollers upon the housing is not very strong, the cap *a* is cast as a separate piece, and screwed on by bolts; it affords the advantage of lifting the rollers out by means of a crane, to effect which would be otherwise very difficult. The plummer blocks *c, c, c, c*, are fitted in a square groove in the housing, and screws pressing from behind keep blocks, and consequently rollers, in their proper place, which is necessary, if round or square iron is to be made. This arrangement is more clearly shown in Fig. 193,

Fig. 193.



Rolling guards.

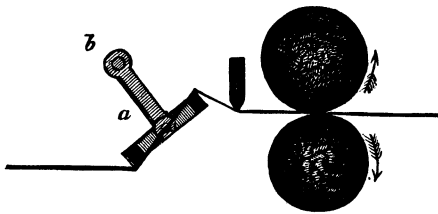
where *c, c*, are the screws pressing behind the plummer block, and of course move the roller lengthwise, if turned on both ends in opposite directions. In this figure, flat rollers are shown, with a view of the scrapers from above. Upon these rollers, a current of cold water is directed, divided into small streams. This cooling tends to preserve the rollers; but it is applied mainly for the purpose of preventing the hot iron from sticking to them, which is not only very troublesome, but causes breakage, and ought, therefore, by all means to be avoided.

b. If square or round iron is to be made, then, instead of the common aprons, guides, *e, e*, 192, are set before the rollers. These are not so much required for square

or flat iron; but they are very much needed in making round iron. A piece of iron, of the form of a frame, is fitted in between the two housings, as shown in Fig. 191, *e*, and in this frame the cast-iron guides slide, being kept in their places by wedges or screws. These guides serve to direct the bar to that groove at which it is required, and in the mean time, to prevent the turning of the rod. The guides and frame are made of cast iron.

c. Smooth hard rollers, twelve, frequently twenty inches long, which serve for polishing hoops, are shown at *d*, Fig. 191. It is not customary in this country to make polished rod; but such rod is frequently made in the Old World. In this case, grooves, according to the size of the rod iron to be made, are cut into the rollers. Such iron very much resembles hammered, or charcoal iron, and is manufactured in imitation of it. These hard rollers must be kept cool by an abundant supply of cold water, else their surface soon becomes rough, in which case it no longer polishes. Hoops must be smooth, and, when possible, of a uniform blue color. The smoothness and color are increased by removing the coating of scales, or hammer-slag, which has accumulated in the preparatory rolls: this is done by a polisher or scraper, represented in Fig. 194, which is an iron frame, *a*, turning

Fig. 194.



For cleaning hoops.

in two necks at both ends, which are attached to the housings. A trunk *b*, with a handle, is at one end, and serves to turn the frame. If a hoop is pushed through this frame, when turned and opened to the rollers, it passes freely, but when turned more or less back, accord-

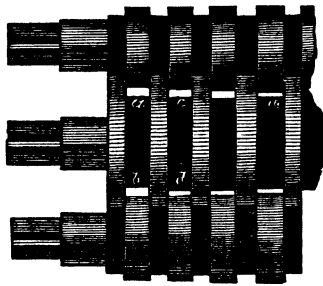
ing to its thickness, it is bent in different directions, as the dark line which represents it indicates. The purpose of bending the iron round such short corners is to break off the scales, or hammer-slag. These scales are an impure magnetic oxide, very brittle when cold, but fusible in a moderate heat; this oxide separates easily from iron, which is not too hot. Therefore, the polishing will be the more perfect the cooler the iron is, when passed through the hard rollers. A bright blue color is generally preferred for hoops. To produce such a color, a very pure but carbonaceous iron, or iron rendered cold-short by carbon, is required. If the iron, or even the cinder in which it has been puddled, contains any phosphorus or sulphur, the surface of the hoops will be found cloudy, and inclined to oxidize more highly, and turn red. A large quantity of silicious cinder in the iron produces the same effect. Good hoop iron is best made in boiling furnaces, from gray pig; this pig iron is rolled into rough billets, and then drawn directly into hoops. Hoops made from highly refined iron, such as fibrous charcoal iron, or that puddled from very good plate metal, are very apt to turn red, and are generally weak. The frame *a* is made as long as the rollers, so as to shift the working place of the rollers, and use gradually the whole surface.

d. Where there are three rollers in the housings, the moving them up and down is not so easily effected as where there are but two, and this motion cannot be effected at all while at work. The best plan we can adopt is to fit the plummer blocks well in the housings, one upon the other, and to adjust the distance between the rollers by means of scraps from hoops or sheet iron, or of pieces purposely forged. The bottom roller rests in the housings; the second or middle one turns in a movable plummer block resting upon the bottom of the housing. The top roller rests in a movable plummer block, and is covered with a strong cap. The whole is safety kept together by the top-screw pressing upon the cap, as represented in Fig. 192.

e. The roughing-rollers are three in number, and are

always of the same diameter; as also are the rollers for square and round bar; but for flat iron or hoops the diameters of the rollers are, of course, different. The middle roller is the largest in diameter, and occupies the place which the bottom roller occupies in cases where but two rollers are used. Fig. 195 shows the arrange-

Fig. 195.



Grooves for flat iron.

ment. The top and bottom rollers are of the same size. The middle roller alone has collars. The grooves in the bottom roller are throughout larger than the grooves in the upper roller. It is so arranged that, if the first groove in the series is *a*, the second is in *b*, the third *c*, fourth *d*, &c. It is apparent that the use of three rollers not only augments their durability, but saves time, fuel, and iron. The garniture of scrapers and guards, described before, is to be doubled, and applied to different sides on the middle and bottom rollers.

f. For the making of wire and small hoops, or rods less than half an inch, and hoops less than one inch wide, the same number of rollers is employed, with this difference, that the rollers are but four and a half or five inches in diameter. The speed of rollers for merchant iron is generally from seven to eight feet per second on the surface, so that the iron with that speed will pass through them. This makes, for twelve inch rollers, 150 revolutions per minute, and for four inch wire rollers, 450 revolutions.

Heavy Bar and Railroad Iron Rollers.

Iron heavier than that one inch square is made by rollers of larger size than the foregoing, with but two in the housings. For this kind of work—to which heavy bar, locomotive wheel tires, rails, and nail plates belong—rollers from fifteen to twenty inches in diameter are used. Their size depends upon the kind of iron to be made; upon the quality of the iron used, whether hard or soft; and upon the quality of the castings of which the roller is made. A particular description of the making of heavy iron is unnecessary, because it differs but slightly from the manipulations and principles with which we are already familiar. This may be applied particularly to the reheating furnace. But, as the making of railroad iron is a matter of particular interest, and as a description of this would include all that need be said concerning the making of heavy bar, we shall describe the process in preference to any other.

a. The weight of railroad bars varies considerably, according to section and length. There are sections of forty pounds per yard, and sections of eighty pounds per yard. In our own county, rails heavier than seventy-five pounds per yard are not at present in use; the most common are from sixty to sixty-five pounds. A rail eight yards long, which is the common size, requires, therefore a pack or pile of from 300 to 500 pounds of iron. Almost every railroad company employs bars of a different section. It is not our province to enter upon an investigation of the construction of rail sections, for the purpose of testing their respective merits; but we will make a few remarks relative to the manufacture of different sections, so far as this subject bears upon the quality and price of the product. Flat rails do not differ in the least from common flat iron; but if we wish to make the best article from the same material, it is advisable to turn the bar in such a way into the rollers that the joints of the pile shall be vertical upon the base of the rail; that is, to run the welding joints of the rough bars through the small section of the rail bar. Very coarse

or porous iron does not make a good rail in this or in any other way; it is apt to split. Such fibrous iron may be greatly improved by rolling the rough bars above five-eighths of an inch thick, and mixing it with cold-short iron. That is, pile a bar of cold-short upon fibrous iron, and thus continue until the pile is complete; the top and bottom courses must be of fibrous iron. In this way it works exceedingly well, and makes the best and cheapest kind of rails that can be made from the same material. The last or finishing groove of flat rails is generally provided with a series of warts, in the circumference of the top roller, giving impressions deep enough for the heads of spikes. The remaining thickness of the iron is punched through after the bar is cold.

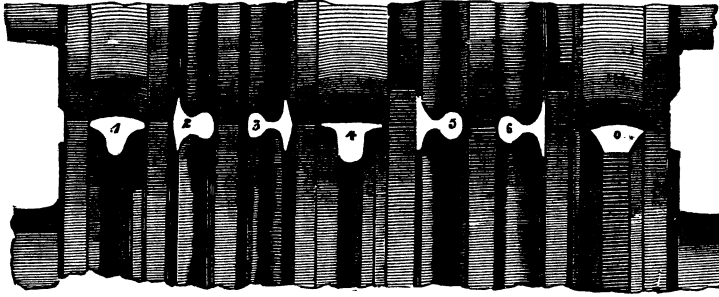
Besides flat rails, which are, and will yet be for a time in use, we find bridge rails employed, which have the form of a reversed U. We find these with parallel sides like the Ω , or with sides contracted towards the bottom, in which case they are called dove-tail rails. These Ω rails are easily manufactured, far more so than the generally employed T rail. The difficulty of filling the flanges is not so great as in the latter rail; and if the railroad companies understood their own interest, we doubt not that they would much prefer the Ω to the T rail; the iron works also would find the former more profitable. In making Ω rails, almost any kind of iron, even the strongest, can be employed, and a good article of course manufactured. But for the cheap manufacture of T rails, the iron must be of a particular quality. The weakest iron works generally the best. Strong and very good iron will not fill the flanges, even though it is made hot enough to work well. Therefore, it follows that a great deal of weak iron is used in making the T rails, which would not be employed if Ω rails were in as much demand by the railroad companies. If there is a special advantage in the T section, we are ignorant of it. We know that, if the Ω section were employed instead of it, there would be a prospect of having better material in the rail. There is but little difficulty in

manufacturing a bridge rail, and as the principle involved in rolling this or the T rail is the same, we will describe the latter.

b. Rollers for shape rails ought to be at least twenty-two inches in diameter, and make from sixty-five to seventy-five revolutions per minute. This diameter is required on account of the deep grooves in the roughing as well as finishing rollers. A pile for a rail eight yards in length, sixty-five pounds per yard, must be thirty-two inches long by ten or eleven inches square; a large groove in the roughing rollers is thus needed to catch the pile. One of the worst of speculations is to make the grooves in the rough rollers too narrow, for delay is thus occasioned. Heavy packs are too porous and too hard to catch the rollers easily, if the grooves are too narrow to make the rollers bite. Cutting the grooves or throwing on sand is of doubtful advantage, for this occasions a loss of time in all instances. At least it is not advisable to make the first groove too narrow, in anticipation of the advantage obtained from cutting it. The rollers may be cut, and made rough in any way we choose; but that ought to have no bearing whatever upon their size, or upon that of the grooves. The loss at the roughing rollers, caused by the iron getting too cold, is, of all others, the most disagreeable, because the iron is generally too long to be reheated, and too thick to be cut through with ease. It is unnecessary to furnish a drawing of the roughing rollers, for they do not vary, except in size, from those already described. We annex, however, an illustration of a pair of finishing rollers for T rails, as the most common. The form of the grooves represented here may be considered as not generally applicable. Different kinds of iron, and the hardness of iron and texture, make a slight difference in the form of the grooves necessary. Fig. 196 shows the gradual transformation of the square billet. It is received by the grooves No. 1, No. 2, and No. 3. These work out both flanges to a certain degree, as wide in the base as actually necessary, but leaving the bottom flange somewhat thicker. No. 4 presses the

bottom and top smooth, and works the bottom flange down to its proper thickness, and somewhat broader.

Fig. 196.



Grooves for T rails.

No. 5 and No. 6 are almost of equal form and size, giving the finishing touch to the rail. The decrement of the grooves is very limited, and there is no difficulty whatever in making a straight rail, even with one groove less. The first groove is cut entirely in the bottom roller, and the form of it is calculated to fill the bottom flanges of the rail with sound iron. The width of the flanges is often kept smaller in this first groove than it is to be when finished; but we think this a wrong proceeding, and only admissible with weak and cold-short iron. Strong, tenacious iron will not fill the flange, if once too small, or, at best, it will make but broken edges, which require a great deal of patching. The proper shape of No. 1 is that in which the bottom of the rail is brought to such a size as to afford sufficient iron to the grooves Nos. 2 and 3 to work both flanges equally down. For doing this, a greater breadth of the groove is needed than the rail will have when finished; and an excess in this direction is, in no instance, disadvantageous. If the breadth is increased in this first groove, the thickness may be diminished, which is very advantageous, particularly with thin flanges and strong iron. The reduction of a square billet to the size of No. 1 is too much for one groove, and a more triangular groove may precede that size. If the rollers are more than forty-two

inches long, and the metal in the rollers good, the grooves may be so arranged as to admit one more in that length. If they are short, or if the casting is weak, a triangular groove may be cut in the rough rollers, where room can generally be spared. Groove No. 1 is better in the finishing rolls, for it bears relation to the final form of the rail, and must vary in shape according to that of the rail. The grooves Nos. 2 and 3 work the rail very nearly to its ultimate size; but they make the rail somewhat too high. This surplus height is reduced in No. 4, where the bottom and top are smoothed, and the bottom flanges reduced to the proper thickness, making the base a little broader than the final measure is to be. Grooves Nos. 5 and 6 serve merely for finishing; they are of the form of the rail when finished—No. 5 somewhat larger than No. 6. In these grooves, the rail receives a uniform reduction in every part, except in the thickness of the bottom flange, and in the height of the rail, which cannot be reduced.

The castings for this kind of rollers are to be of good metal, of strong, but not very gray cast iron. Rollers for flat iron must generally be good castings, on account of the flanges or collars; these are mostly high, and liable to be affected by pressure and sudden change of temperature, which frequently injure a roller so much as to make it, in a comparatively short time, unfit for service. The collars on rail iron rollers, and all heavy flat iron, must be strong, and with the best iron not less than two inches thick; this thickness is to be increased, if the length of the roller will admit of it.

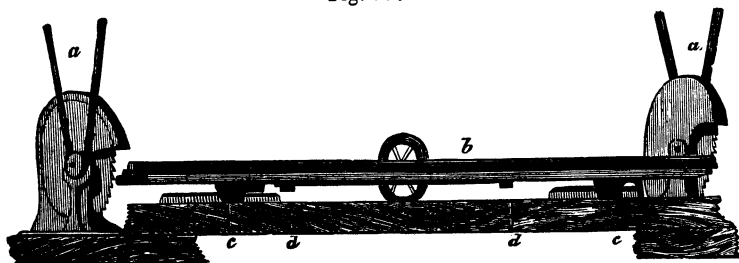
c. The heavy packs or piles of railroad iron are, in many establishments of England and Wales, brought from the first heat to the T hammer for welding. This practice is not common in this country, nor anywhere else; it is necessary where iron is employed which is too weak to bear a strong heat. A heavy pack of weak iron, if heated to a welding heat, will split in being roughened down. To prevent this, such piles are to be brought to the hammer, which will give the iron a small compression, and an imperfect welding, making it less liable to

open in the rollers. Well-worked iron, which will bear a welding heat, is not very liable to open in the rollers, thus saving the expenses of shingling. Instead then of shingling the pile, it is pushed through the roughing rollers and reduced to a six or seven inch billet, which is returned to the reheating furnace. This is a very advantageous way of working, in case the iron is of good quality. The carrying of heavy piles from the reheating furnace to the rollers is performed by means of iron cars, just high enough to reach the furnace door, and not too high to reach the rollers. In case the rollers will not bite, this car is made use of to strike the end of the pile, and force it into them. Such a car must be very strong, and entirely made of wrought iron; it should have on the top a series of friction rollers, two inches round; these receive and discharge the heavy piles more easily than traverse binders. At the roughing rollers, two workmen before and two behind are needed, one on each side using the tongs and the other catching with a suspended hook, close to the tongs, in order to help, or, in fact, to carry the whole weight of the end of the bar; the roller and catcher before and behind the rollers, using their tongs merely to turn the billet. At the finishing rollers, there should be at least two workmen before, and three behind the rollers; and, if the rails are long or weak, three before and three behind having each a hook suspended on long rods; these hooks follow the rail in its motion, and support it against bending by its own weight.] The following method of raising the heavy shingled masses to the rollers is stated to be used with success in an English rolling mill. A single acting steam cylinder is mounted in a frame at the top of the roll standards; and the piston rod, which passes up vertically through an adjustable bearing is connected to a cross piece which can be moved up and down in two vertical slides. Outside of the guides the cross bar has attached to its ends a series of connecting links, to which the two inclined feed plates or tables, one at each side of the rolls, are coupled by means of wrought-iron rods, so as to be firmly connected with the cross bar, and

to follow its movements in a vertical line. The cross bar being connected to the piston rod, is lifted by the pressure of steam in the cylinder when admitted below the piston. The effect of this movement is that the guide plates at both sides of the mill are raised simultaneously to the height required for passing the article back over the top roll, and the revolution of the top roll itself—its upper side being, of course, moving in an opposite direction to its under side—takes the article back to the front of the rolls by friction.*

[After a rail is finished in the rollers, it is carried to the saws, to be cut square at the ends while hot. These are circular saws, with coarse teeth, and about three feet in diameter, made of sheet iron, or, as in some cases, of steel. They move with great rapidity, and cut a rail through in a second or two, making from 1200 to 1500 revolutions per minute. Fig. 197 represents a sawing

Fig. 197.



Saw machine for squaring the ends of railroad and heavy bar iron.

machine for cutting off the ends of rails and other heavy iron. There are two saws moving at the same time, and kept in motion by the straps *a, a*. The distance between these saws is in some mills somewhat greater than the length of the rail, so that but one end will be cut at a time, after which the rail is moved longitudinally, and the other end cut off. Equal lengths in rails are rarely insisted on by the railroad companies, and almost any length is suitable which is within given limits. With

* Engineering, March, 1867.

good iron, and by proper care, the soundness of the bar to the very ends will be secured; and only a few inches are lost in squaring. Ill-worked iron frequently loses from one to one and a half feet at each end, which is equal to from twelve to twenty per cent. The hot rail is placed and moved towards the saws on an iron bench, which slides in the parallel prisms, *c, c, c*. It is moved by a long horizontal shaft, lying between the saws. On this shaft—which is turned by an iron handwheel of the shape of a light flywheel—are two small pinions, one on each end, which work in corresponding racks *d, d*, fastened to the bench, and moving it to and from the saws. The cutting of a heavy bar of hot iron is a beautiful sight—the rapidly moving saw throwing off a profusion of small particles of iron, which burn, in darting through the air, with a vivid and brilliant light. They would injure the workmen engaged at this business, if the saw were not covered by a protecting screen. The lower part of the saw runs, at many establishments, in cold water, to prevent its getting hot, in consequence of the heat and rapid motion.

From the saws, the rail is put upon the straightening-bench, which is a long, straight, cast-iron plate, ten or twenty inches wide, having on one edge a projecting rib. This bench is used for common flat and square iron, for flat rails, and rails whose top and bottom are of equal size; but for bridge rails or T rails, such a bench will not answer. Any iron, or rails, the one part of whose section is composed of thinner parts than the other, will not remain straight after it has been straightened when warm. The thin parts will become cold sooner than the thick parts; this produces an unequal contraction, and gives a curvature to the formerly straight bar. A Π or T rail is generally broad and thin, in its lower part or base, in proportion to its top, and, consequently, if straightened on a straight bench, it will gradually assume a curvature concave at the top of the rail. To prevent this, convex straightening benches are employed, whereupon the rail is bent, by means of heavy wooden mallets, into a convex form, which will straighten as the

rail gradually cools off. The convexity of such a bench depends on the section of the rail and the quality of the iron; it is generally from an inch to an inch and a half to every yard of the rail. As the rail gradually cools off, and straightens itself, it is removed from the bench to large platforms, provided with two parallel rails distant from each other nearly the length of the rail, along which the rails easily move. Three or four such platforms in succession are required under one shed; their form must be nearly square—that is to say, their extent, lengthwise and crosswise, should be equal to that of a rail. On the first platform, the rails are overhauled by means of coarse files, and any imperfection or unsoundness of iron exposed. Those which cannot well be improved by patching are removed. Between the first and second platform a very heavy cast-iron anvil is placed, on which the final straightening of the rails is performed; for that purpose, heavy iron sledges weighing from twenty to thirty pounds are used. Between the second and third, fourth and fifth scaffold, the rails are patched. This consists in fitting in small pieces of iron into the defective parts. In the rolling of T rails, there is sometimes difficulty in bringing out their flanges; in this case, we succeed far better with cold-short, or impure, dirty iron, than with pure, strong, and fibrous iron. This difficulty increases with the diminished thickness of the flanges, and cannot be avoided if the iron is very strong, or free from cinder. Weak iron, or cold-short iron can be worked to great perfection, if the pile is turned in such a way that the joints of the mill bars fall perpendicularly upon the bases of the rail. If taken in the opposite direction, even the weakest iron will not make full, broad, and thin flanges. To what extent the quality of a rail is impaired, in consequence of these practical difficulties, it is not our province to investigate. But we may say that the quality of rails might, in most cases, be made, from the same materials, far superior to what it now is. If the constructing engineer of a railroad would reflect upon the best practical form of a rail, and alter its section accordingly, there is no doubt

that great advantages might be realized. With respect to \square rails, or rails with equally thick flanges, the above difficulty does not exist, at least not to so great an extent.

Sheet Iron.

The making of sheet iron is a branch full of intricacies and difficulties; but once thoroughly understood, it is very simple. The main difficulty we encounter depends upon the quality of iron from which it is made. Charcoal iron generally works well; but some kinds of puddled iron do not make good sheet iron. Sheet iron was made in ancient times by means of forge hammers; it was flattened down by broad-faced hammers on large anvils. This method is still practised in the eastern parts of Europe. At the present day, and in our own country, sheet iron is rolled. It is made partly from charcoal blooms, and in some places from puddled iron.

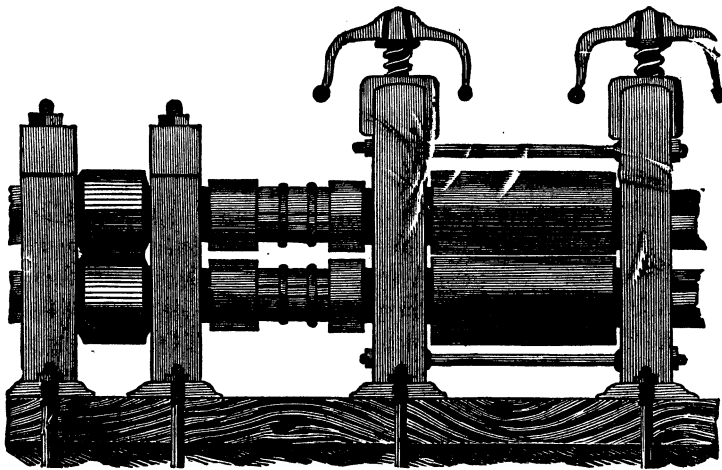
a. In all cases in which thin sheet iron is to be made, the iron must first be converted into flat mill bars. Charcoal blooms, as well as puddled iron, undergo the same treatment, with this difference, however, that good charcoal blooms do not require a welding heat.

Puddled iron is to be piled, and a pack of rough bars welded and rolled down into flat mill bars. These bars are from four to six inches wide, varying in thickness, according to the number of sheets to be made from them. Heavy sheet iron and boiler-plate are to be made from mill bars, if we want a good article. Sheet iron is principally made from charcoal blooms shingled down into slabs; sometimes from puddled rough bars, piled, welded, and shingled by the T hammer into slabs. By neither method is good boiler-plate made; a second reheating is, in all cases, to be resorted to, if we want the best article the material is capable of producing. In the manufacture of sheet iron, our main attention must be concentrated upon the quality of the iron, and the power at our service. All other matters are of subordinate importance, and have little bearing upon the success of our operations. Clean, white, fibrous iron, and a sur-

plus of power, are the most essential elements in making good and cheap sheet iron.

b. The machinery for making sheet iron does not materially vary, except as regards strength, from that used in making bar iron. The housings are generally heavier, in Europe often made of wrought iron; the junction shafts and coupling boxes stronger; the fly-wheels heavier. The length of the rollers is, in most cases, but three feet between the gudgeons; seldom three and a half feet for thin sheet. For the rolling of boiler-plate, we find rollers four and even five feet long in use. The diameter varies according to the length. A short roller may be of a smaller diameter than a long one; and weak cast iron, of course, will make a larger diameter necessary than strong castings. In Fig. 198.

Fig. 198.



Rollers and pinions for sheet iron.

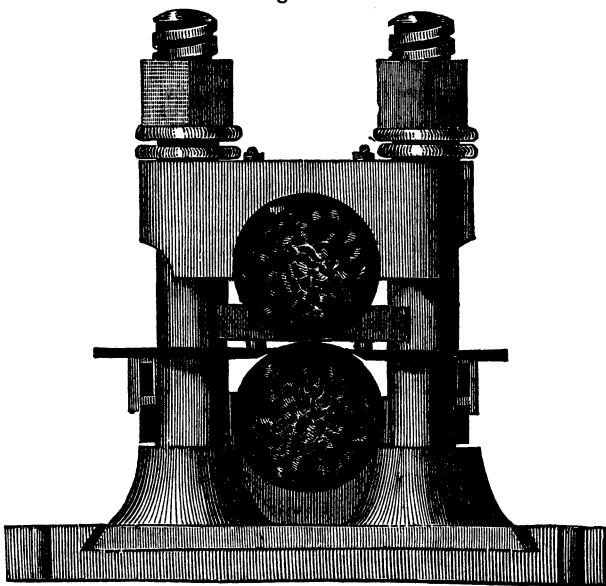
a set of sheet rollers is represented. The pinions and pinion standards are not generally employed; they are unnecessary, and even disadvantageous, for making thin sheet. But for roughing down, when the plates are thick, or for making boiler-plate they are advantageous, and save a great deal of breakage. Slabs which are one and a half, or two or more inches thick, lift the top

roller very high, and suddenly drop it; this, of course, produces a heavy shock all through the machinery. To avoid this shock, the top ought not to touch the bottom roller; but then the pinions are necessary; without them the top roller will not move, and unless this moves, the rollers will not bite. In cases where the top moves independently of the bottom roller, the first is generally balanced by counter weights, applied either below or above the rollers; these weights keep the top and bottom rollers apart. We think that the arrangement indicated in Fig. 187, for keeping the top roller up, is far preferable to any other. Wrenches on the top of the screws forming a cross, so as at any time to expose a handle to the workmen, before the rollers are to be used. The distance between the rollers must be perfectly controlled by the foreman, because he regulates the thickness of the sheet by these screws. Of all the improvements made relative to the regulation of the distance between the rollers, none is preferable to the above simple mode.

c. For making very thin and polished sheet iron, cast iron housings are not sufficiently strong, unless very heavy, and of the best kind of iron. In this case, wrought-iron standards are preferable; and, as there is no difficulty in obtaining heavy and good wrought iron, at reasonable prices, in Eastern Pennsylvania, it may, in many instances, be advantageous to employ such standards. In Fig. 199, *a, a*, represent wrought-iron pillars; these are fastened by being cast into the bottom plate. Each of these pillars is provided with a screw and nut; the advantage of taking small, very minute grades of pressure, or decrement, upon the top roller is thus secured. For the making of thin sheet iron, this is a very convenient and essential arrangement. The aprons are broader than at bar-iron rollers, which is indispensable. If heavy plates are to be rolled, even small friction rollers in the apron are to be added on the work side. The friction of heavy iron upon the apron is great, and the employment of additional hands would be necessary, if this friction were not diminished by the

above friction roller. Sheet rollers move with various speed, and the foreman ought to have it in his power

Fig. 199.



to give to them just the degree of speed required. The speed necessary for these rollers is from twenty to forty revolutions. In a well-conducted establishment, there are roughing rollers, finishing rollers, and hard or chilled rollers. We generally find only the first two, but in some establishments the last.

d. For making boiler-plate, but one pair of rollers is needed, and the slab rolled down in one heat. The slab, as received from the T hammer, is generally from twelve to eighteen inches long, from seven to ten inches wide, and from two to three inches thick. It is heated, in a reheating furnace, to a bright red, but not welding heat. The dimensions of the sheet to be rolled from a given slab are produced by turning the slab more or less, and increasing in one direction. The surface of the iron is repeatedly chilled by sprinkling cold water on it by means of a broom; this loosens the adhering scales,

which may then be removed by turning the plate, or by the broom. This operation must be particularly attended to when the plate is nearly finished. Polish and great smoothness are not required for boiler-plate. Uniform thickness and good quality of iron are the main requisites.

e. Sheet iron thinner than boiler-plate is generally rolled from platines, or from cuttings of flat merchant bars. That which is heavier may be made from one length of the flat mill bar ; and two, or even three thicknesses, when sufficiently heated, are welded together in the sheet rollers. Common sheet iron, as No. 15 and higher numbers, is made from one thickness of the mill bars, which, heated to a cherry-red heat, is run through the rollers in single sheets. At subsequent heats, two or even three may be rolled together. When heated, the mill bars or platines are brought from the oven in pairs, which are pushed singly through the rollers. This keeps the workmen actively employed ; for, while one plate is between the rollers, the other is returned over the top roller, the one thus closely following the other. If three plates are at once in motion still more active manipulation is required, for, while one plate is between the rollers, the two other plates are in the tongs on each side of them. In the first heat, the iron is reduced as much as possible ; and to what extent it may be brought to the desired form, depends on the power of the engine, and the dexterity of the workmen. In this heat, the breadth of the sheet is determined, in case the platines are not already cut to the proper length.

After this operation, the iron, which already assumes the appearance of sheet iron, is returned to the heating oven, or, as in well-conducted establishments, it is heated anew in a more advantageous oven. From this second heat, two sheets are taken and rolled together, with the caution that after passing them two or three times through the rollers, they are separated, and their sides reversed, partly to prevent the adhesion of the plates, and partly to impart a smooth surface to both sides of the sheets. Sheet iron for the manufacture of nails, and

other common purposes, is in this heat generally finished; but a deficiency of power, or want of skill on the part of the workmen, frequently makes it necessary to give it an additional heat.

Sheet iron of less thickness and of higher polish, such as that used for stove pipes, requires another heat, and sometimes several additional heats. An ordinary, smooth surface will be produced by passing sheets, two by two, through rollers of tolerable hardness. But if, in this heat, the sheets are passed singly through the rollers, before which a scraper is put to clean the surface from the coarsest part of the adhering scales, a finer surface is produced. For this purpose, common rollers of good close castings are sufficient. But if a still finer surface is required, hard and highly polished rollers are necessary. To such thin sheet iron a high degree of power must be applied, because the iron when passing through the rollers, is very nearly cold. For this reason the rollers are made only from twenty-two to twenty-four inches in length, while their diameter is sixteen or eighteen inches; the housings of great strength, and the power applied greater than in any other case. Highly polished sheet iron of larger size than twenty inches in width, and four or five feet in length, is seldom made.

In making sheet iron, it is sometimes difficult to obtain the precise color which the manufacturer desires. Such a color is a bright, light blue, or that of Russian sheet iron. Experience proves that from impure iron we cannot obtain a bright, silvery-looking surface. But the color of the best and purest iron may be destroyed by the influence of the fuel. To give a bright surface to sheet iron, we require, in addition to hard and well-polished rollers, the removal of the scales, as far as possible, from the surface of the white or pure iron, which ought to shine through the thin coating of magnetic oxide. The brightest colors are received from the whitest iron. It is thus seen that the color has no relation to the purity of the metal. We have seen very beautiful sheet iron made from very cold-short iron containing phosphorus, and very cloudy-looking black sheets from

the best and toughest charcoal iron. If we wish to make a light, fine-looking sheet iron, a portion of carbon, or even of phosphorus and silicon, will be advantageous. In very thin sheets, the most cold-short iron is malleable; and, therefore, in this instance, it is useful. White iron—whether the whiteness arises from impurities, or from remarkable purity—separates easily from its scales, and is on that account preferable to metal of any other color.

f. The color of sheet iron is affected not only by the quality of the iron, but also by fuel, and by construction of the heating ovens. Sulphur imparts a black color to iron if present only in very minute quantity; and it may be regarded as an impossibility to make a fine-looking sheet iron in cases in which sulphurous coal is employed. Though the iron in such cases, may be of the best quality, the sheet will appear of a cloudy, black, or of a dirty, dark blue color. Pure carbon will not injure the color; but when present in connection with sulphur, the color of the iron will be entirely spoiled. Therefore, if the sheets are well cleaned in the third heat, all our attention should be concentrated upon the endeavor to protect them against the influence of sulphur, pure air, and against the silicious dust which is thrown out by anthracite coal. This can be effected by high arched ovens, which will prevent the flame from playing on the oven. We should select fuel free from sulphur; and, if we employ anthracite, we should secure so weak a draft in the oven that no silicious dust shall be carried over from the grate to the furnace. Charcoal is the best fuel. In fine, by employing charcoal, clear iron, a high oven, well-polished rollers, and a sufficiently strong power, we shall experience no difficulty in making the finest kind of sheet iron. In most kinds of sheet iron cleaning the iron by means of acids is a waste of time, and an unnecessary expense. It may be cleaned by means of a scraper, on the principle applicable to the cleaning of hoops, without difficulty.]

Russia Sheet-iron.

The peculiar gloss and beautifully finished black surface upon Russia sheets have been the subjects of much discussion and research. Some years ago we paid some attention to the discovery of the cause. There can be no doubt that a graphitic surface, superinduced, will bring about a similar gloss. Some have supposed that a phosphuret of iron created upon the surface will produce the same effect, but while a glaze may be thus produced, it is not that of the Russia sheet iron. From what we have learned from a friend who travelled in Russia, and made the manufacture of this iron an object of inquiry and research while there, it seems a well-settled fact that a great degree of the beauty of the surface is due to the exceedingly fine iron which is used. We have in our possession a piece of Russia iron which is so brittle that it will not bear shearing. This may give grounds for believing that a phosphide enters into the constitution of the sheet; but we have good reasons to believe from the exceedingly rare occurrence of any such sheets, that nothing of a decisive character can be deduced from such an instance. We have in our possession a sheet-iron stove cylinder which was made some four years ago, by a patent method, which as we are permitted by the owner, who is a professional gentleman, we shall give in proof of the supposition we have presented, that the surface in the Russia iron may practically be produced by the superficial formation of graphitic iron. The following is in brief the complete process:—

The sheets are of a thickness equal to No. 22. Equal parts, by weight, of chalk, porcelain clay and graphite, ground in paint mill to the consistency of molasses. Put the plates in while still warm; withdraw them as soon as dipped, and put aside to dry. When dry, pack eight to ten in a bundle; heat to dark red—continue rolling, and temper in annealing furnace.

Prepare three strong wooden boxes to receive plates edgewise.

Box 1. 1 part concentrated sulphuric acid, and 3

parts water. Keep the sheets in until entirely free from scales. (Short time.)

Box 2, with lye. 1 part potash, diluted with 20 parts water, and filtered. Plates remain till testing strip indicates greenish-blue glossy tint; then remove them to box 3, with clear running water—thoroughly wash the sheets.

Dry the plates by application of saw dust.

Put them in oven—vertically—two inches apart. Oven to be heated with light, dry wood (hemlock or pine) and provided with a crown of fire-bricks over the furnace, separating heating chamber from furnace, and perforated with numerous small holes for distribution from below. The fire is lighted after the oven has been charged with plates to its full capacity. The first result consists in the deposit of a light skin, or layer of condensed smoke, over the entire surface of the plates. With the increase of heat and the consumption of the smoke, this is carried off, and the plates assume a bluish-black, glistening surface. For the purpose of closely watching and controlling the operation, one or more sides of the oven are provided with suitable openings for the insertion of trying strips. A careful examination of these testing strips will show the gradual production of a carburet on the surface, which, at first, appears scaly, and may be scraped off with a knife. Soon, however, the carburet will be found to have embodied itself firmly with the iron, and is no longer removable in the above manner. From this period, the heat must be checked, and the plates allowed gradually to cool. When the plates are removed from the oven, their surface will be very sensitive to the action of a blow with a polished hammer, or to the pressure between polished rolls, such as are used for rolling out copper, silver, or sheet steel. The hammering is best accomplished by means of a first, or fore hammer, and a polishing hammer, both of which should be light—say, thirty to forty pounds.

After hammering, or rolling, temper. Tempering chamber lined with plates of fire-bricks. Tightly closed to exclude air; fire kept up till heat of iron approaches

the point at which it changes from black to dark red. Opening for insertion of trying strips. Be careful not to overheat the plates. Plates will lose very little of the smoothness and polish—now ready for market—but final treatment with light hammer, or polished rolls, makes them better.

For a Silver Gray Tinge.—Immediately polish plates after removal from water—and, afterwards temper—like black; only at the beginning of the tempering process inject small quantities of rosin into the tempering chamber. This, by forming a heavy layer of condensed smoke on the plates, much preserves their former color, besides producing a lustrous surface.

The stove cylinder we have has been exposed under the same conditions under which the genuine Russia iron has been exposed and has resisted rusting where the other has been attacked. Immediately after finishing, the sheet may be rubbed over with a white cloth with all the perseverance and pressure possible to give it with the hand, and no signs of soil will appear any more than from polished steel.

It is to be hoped that this patent, which hitherto has been more an object of experiment than of commercial value may be put to the test in the large way, as there is no grade of Russia iron superior to that which has been made by this process.

There have been a large number of patents taken out for different methods of making imitation Russia sheet iron, but none of them have equalled the article as imported, unless we except the one just described.

Buckling, is the term used by the sheet-iron workers, where the sheets become convex or concave in various places upon the same sheet after annealing. This has been remedied, or prevented, by piling the sheets one upon another and placing a heavy weight upon the pile just before pushing them into the heating or annealing oven.

Swallow-Tail, is the term used to describe that condition of the roll where the ends are higher than the centre, thus running the sheets out longer at the sides

and corners. This may be due to an extremely small increase in the diameter of the rolls at the ends, and this may be remedied by cooling the roll by water or steam, in that part needing contraction or elevation. This fact is taken advantage of by the workman, who can, by the simple application of water, alter the shape of the roller to suit his wants exactly.

Later Improvements in Hammers and Rolls.

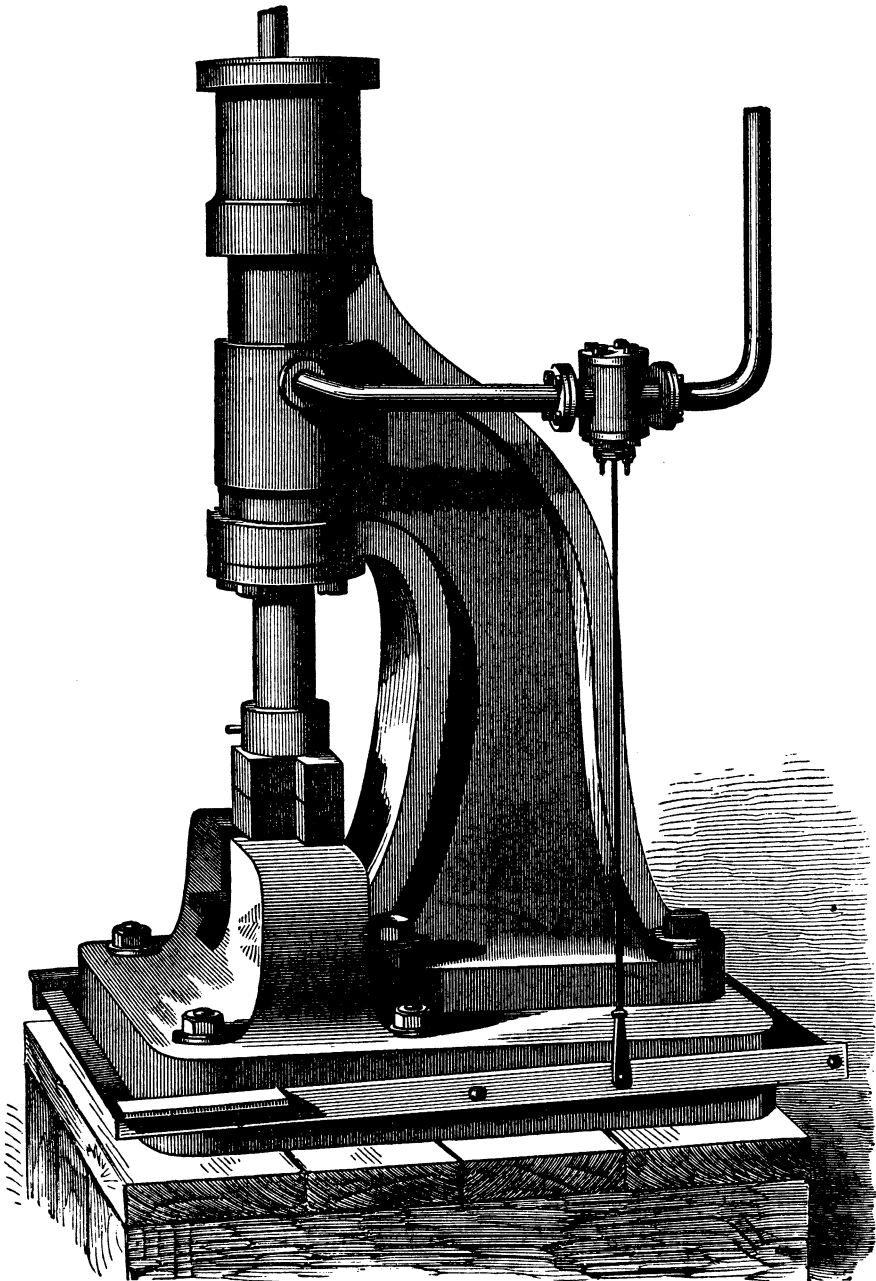
In 1842, Mr. Nasmyth visited Creusot (250 miles southeast of Paris), and saw the primitive single-acting steam hammer of Bourdon in operation, realizing the fact that it is quite possible for two inventors to elaborate the same idea independently of each other, and almost simultaneously. We understand that the French patent of Messrs. Schneider bears date the 19th of April, 1842, and the English one of Nasmyth, the 9th of June in the same year.*

Since the first year of the application of steam by Nasmyth to the hammer, nothing very important in the principle of this application of steam to this purpose has been invented. Some practical modifications, however, rendering the hammer more enduring in its parts and more exactly under the control of the hammer-man, have been induced. The following have been presented to the American public as improvements.

David Joy's Hammer.—The peculiarity of this hammer consists in its simplicity of parts, the valves being part of the ram, as may be seen by the following cuts, Figs. 201 and 202. The action will be plainly understood by an examination of the cuts. The admission of steam and consequent speed of the hammer are regulated and governed by the foot of the forger, as plainly shown in Fig. 200. A hand-gate may also be placed on the steam pipe, if desired. Thus a slow and a light blow, or a rapid and a heavy one, can be obtained at pleasure. In Fig. 201, the ram is down, and steam being admitted at

* The Engineer, Feb. 1, 1867.

Fig. 200.



David Joy's hammer.

A, and passing as indicated by the arrow nearest A, around to B, throws C up. When up Fig. 202 shows the connection between B and the exhaust for the steam

Fig. 201.

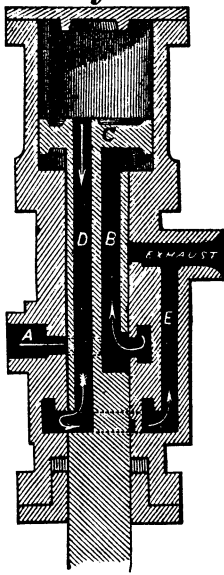
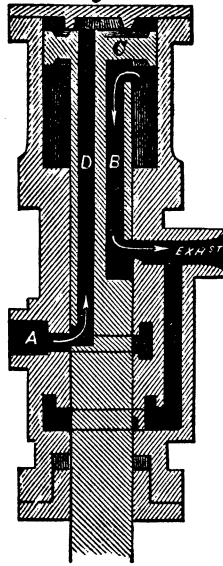


Fig. 202.



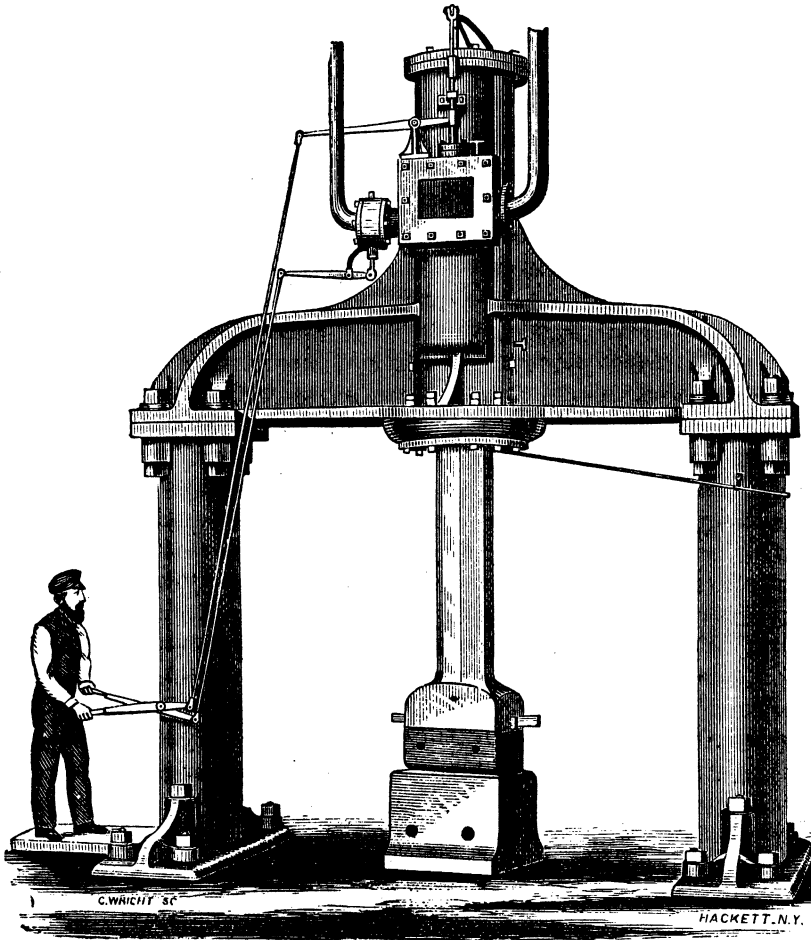
under C, at the same time the steam entering A along D is admitted to the upper side of the piston, and it is then thrown down again as in Fig. 201.

We supposed that the absence of so great a part of the piston rod for the purposes of steam channels would weaken the resistance or "thrust" of the hammer rod, and considering it in the light of an objection, we received the following in answer from the patentees Messrs. Merrick & Sons, of Philadelphia, Pa. "1. The ram is a forging of Bessemer steel. 2. The amount of metal taken out of the rod, compared to its mass, as will be evident by a glance at the cross section, cannot possibly so weaken as to make the objection of any weight." The hammer is certainly desirable in view of its simplicity, and appears to be used in Brooklyn, N. Y., with great

efficiency requiring, however, some good degree of skill on the part of the operator.

Dudgeon's Steam Hammer.—This is supposed to be an improvement in that “a wider range of efficiency is secured than can be obtained on the usual form, an arrangement is made whereby the ram is prevented from

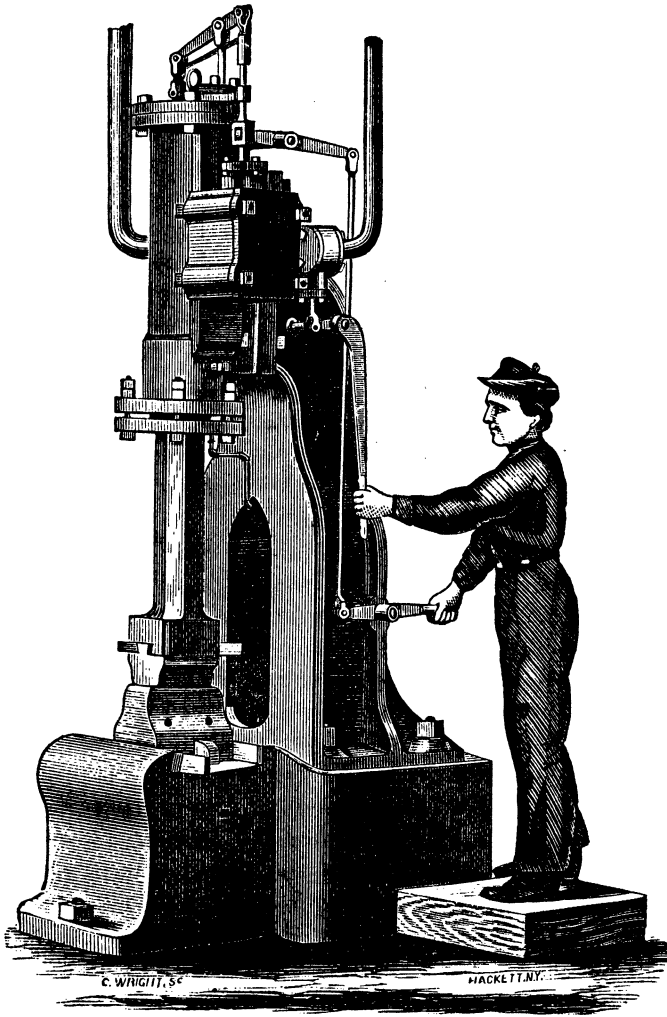
Fig. 203.



tearing off the cylinder cover, an accident which not unfrequently occurs with steam hammers constructed after

the usual plan. The rams are all made of wrought iron, with Bessemer steel dies on the two smallest sizes." This hammer is used in several important establishments in

Fig. 204.



Philadelphia, Boston, Trenton, and at Washington. The accompanying cuts, Figs. 203 and 204, sufficiently exhibit

the working of the parts and the manner in which the piston in returning may "cushion" itself by steam from the steam chest. Two sizes are given in the engravings, although in either the principle is the same.

A very neat improvement by J. I. Kinsey, the superintendent of the Lehigh Valley Railroad Machine Shop, at South Easton, Pa., works very easily and satisfactorily, as we have frequently had opportunity to notice. It consists in a third valve which accomplishes one object of Dudgeon's hammer, by checking the scape of exhausted steam, and thus forming a cushion for the piston. It requires a third handle, but works readily and is under perfect command. A serious objection to some forms of hammers is found in the attachment of the hammer block or anvil to the main frame or standard. The jar upon the anvil, when thus forming one casting, has a strong tendency to cause a fracture.

It is scarcely necessary to say that in all cases the skilful use of any steam hammer requires considerable practice, and this may be had by the use of the hammer upon a block of wood, until the learner has acquired skill enough to practise upon the hot iron.

Complete and powerful hammers for forging may be found at the Penn. Iron Works, Danville, Pa., also at Cold Spring, N. Y., and at Trenton, N. J., in the rolling mill at the latter place.

Compressed Air Hammers.—Hammers of this description have been in use for some years, but only for light work, such as planishing or ordinary smithwork, but the principles may allow of larger kinds and yet not for very heavy service. The only good representation we have seen has been that of a hammer of Dawes's, of Wolverhampton, which struck with the small weight of forty pounds, running, however, from 200 to 300 strokes per minute. An eccentric upon a shaft with a band wheel works the piston rod, which condenses air into the hammer shaft cylinder with sufficient force to raise the hammer shaft or rod vertically. The piston of this hammer shaft then in its turn condenses the air in its own cylinder with such force as to cause it to react as a powerful

spring, acting, with gravity, to throw the hammer down with considerable force.*

The Gunpowder Hammer.—The following description will convey a good understanding of a hammer which, while it was in this instance used for pile-driving, had been used for more than two years, antecedently, for forging, and attempts have been, and are now being made, with a view of introducing it into metallurgical practice. Thus far, however, adaptation to forge purposes has not been satisfactory:—

On Tuesday, June 15th, Shaw's Gunpowder Hammer was exhibited in driving piles, to a numerous assemblage of gentlemen, at Lynn's shipyard, on the Delaware. A committee of engineers, consisting of Mr. W. W. Wood, Chief Engineer U. S. N.; F. P. Lovegrove, Inspector of steam boilers in Philadelphia, and Mr. H. L. Hoff, of the Eagle Iron Works of Philadelphia, who witnessed the performance of the hammer, have made a report, from which the following extract is taken. They say:—

"That the machine is operated and controlled by a man and boy, and that it can be made to strike forty-eight blows per minute; also single blows at the will of the operator. And that although the pile was driven in tough soil, it was not hooped, and was driven thirty feet without in any way injuring or splintering it, showing the extraordinary pushing character of this method of pounding; and that one-third of an ounce of powder throws the hammer a distance of eight feet; and that the hammer was allowed to fall a distance of eight feet on a solid block of wood, placed on top of the cylinder, and it forced the pile only 13.16 in the ground; and that the next blow powder was used, the hammer allowed to fall the same distance, and it forced the pile four inches in the ground, showing conclusively that the blows are not only made rapidly, but that each blow is five times as effective as by the falling of the weight alone. It is added, in conclusion, that this novel application of gunpowder is an unqualified success for the purpose of driving piles, promising as it does a saving both of time and labor, which should commend its use to all who require machines of this character."

A large number of others who witnessed the experiments at the time, have also united in a statement that it is their conclusion that this method of operating hammers is the correct one for all heavy work, and that it is of simple construction, easy management, and will prove its usefulness to the mechanical world, compatible with the want in great engineering.

* A good drawing may be seen in *The Engineer*, Nov. 30, 1866.

Shingling by Compression.—This has been attempted and, so far as effects are concerned, with entire success. The welding is complete, the expulsion of cinder thorough and the resulting bloom very satisfactory. But the difficulty thus far has existed in the mechanical method of producing the effect. Mr. Player, of English celebrity, has invented a method which appears to be in some degree practicable. We give the whole method as sent us by his partner, Mr. Henderson, reserving our remarks till the close. The following is the specification:—

This invention has for its object to facilitate the forming a ball, bloom, or slab, of iron or steel, after it has been deprived of a portion of its carbon and impurities by the puddling operation, and consists in transferring the semi-fluid malleable iron or steel, into a form or mould outside the furnace in which the iron operated on has been converted, and subjecting the metal to a heavy pressure in the form or mould, thus causing it to agglutinate or weld together into a ball, bloom, or slab—instead of “balling it up” by hand in the furnace in which it has been converted, which is the method at present adopted with puddled iron or steel.

For this purpose, the crude or pig iron to be made into malleable iron or steel, is melted in a cupola or reverberatory furnace, and the fluid metal is there agitated, either in the same furnace in which it is melted, or otherwise, either by manual labor or steam power, or both, in contact with fluid oxide of iron and other matters (as is usual when puddling iron), until the mixture boils or froths up and the iron becomes malleable; or, as it is termed, is “brought to nature.” When in this state, the semi-fluid mass is forced or drawn out of the furnace in which it has been agitated, into a cast, or wrought iron receiver, form, or mould. In this receptacle it is then compressed to such degree of density, that it can be removed from the mould and forged or rolled to the size that is required.

Whether the pig or crude iron operated on be converted into malleable iron or steel by machinery or manual labor, the process will be the same after the metal has been brought “to nature,” or, in other words, made malleable. I will suppose a common puddling furnace to be used.

Figure 205, of the annexed drawings, is a front elevation of a common puddling furnace in which slight alterations have been made to adapt it to my process; Figure 206, a back elevation; Figure 207, a cross vertical section; and Figure 208,

Fig. 205.

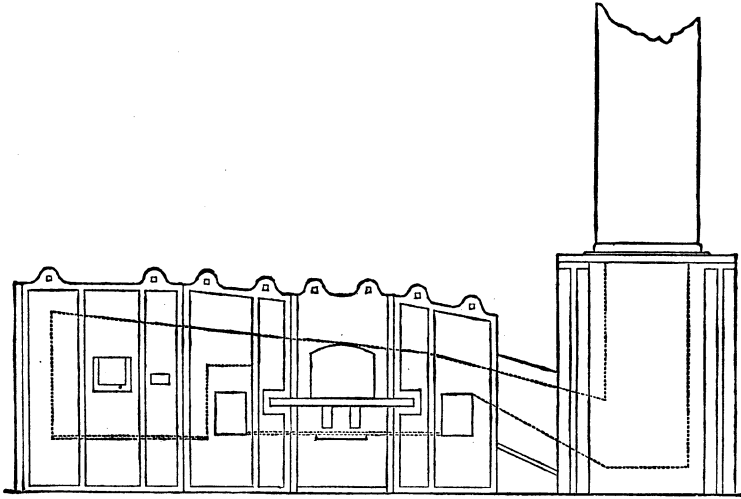
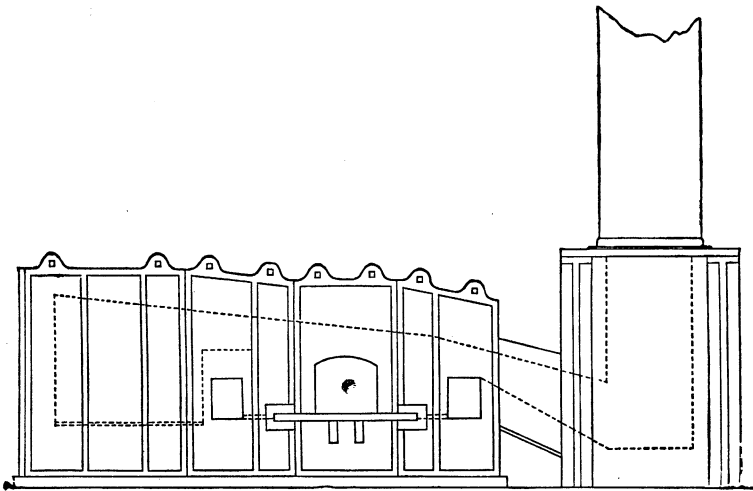


Fig. 206.



a horizontal section thereof. Figure 209 and 210, are vertical sections, taken at right angles to each other, of the hydraulic ram for pressing the puddled metal into a bloom; Figure 211, is a plan thereof; and Figure 212, is a horizontal at the line *a a*, of Figure 209.

Fig. 207.

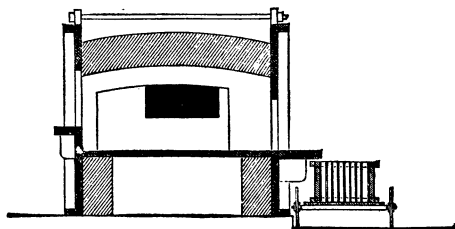


Fig. 208.

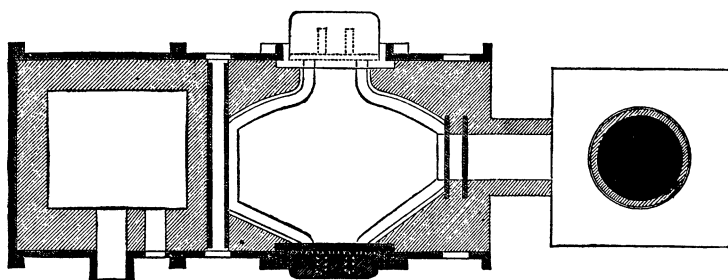


Fig. 209.

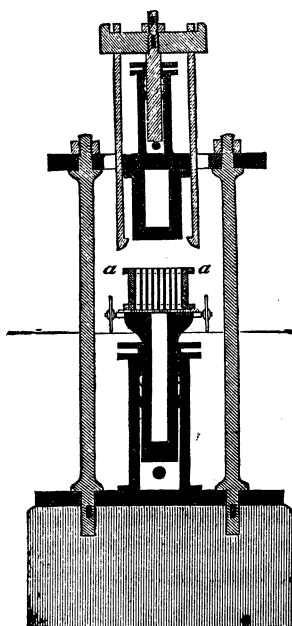


Fig. 210.

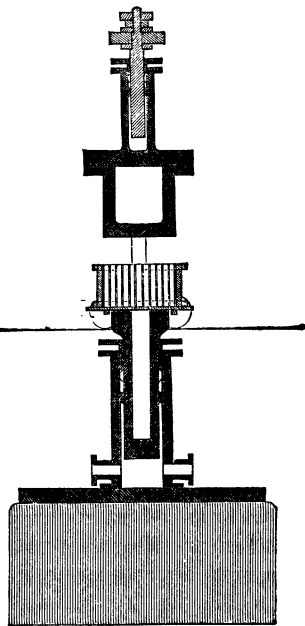


Fig. 211.

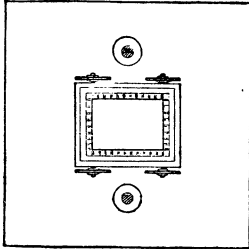
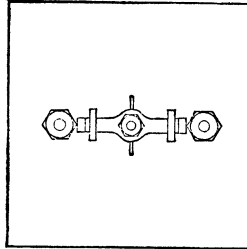


Fig. 212.



I prefer to have two doors opposite each other; one, the working door, is of the usual construction; the other door opens to the level of the hearth; it may be constructed and opened with a lever in the usual way. Before the furnace is charged, this door is shut and wedged close, and fettling of red iron ore or other material is rammed from the working door against the lower part of it, so that the fluid mass, when melted in, or, by preference, poured into the furnace, cannot run under the door.

The operation of puddling is then commenced, and the charge worked in the usual manner, until the metal falls and is fit to ball up; it is then turned over in the slag and exposed regularly to the flame for a short time. In making steel, the operation is hastened towards the end. The slag is then partly run off in the usual way, the lower door is then opened, any fettling in front of it removed, and the whole or part of the charge, as may be required, is pushed or forced with a rabble or tup (which is introduced at the working door) out at what is termed the back door, into a form or mould hereafter described. As soon as the furnace is clear, which only takes two or three minutes, the back door is shut and the furnace refettled and charged again with metal, run in by preference in a melted state from a cupola furnace. The saving of time in puddling one charge by this method is about twenty-five or thirty minutes. That is the time the pig takes to melt, and the time the charge takes to ball up.

The mould into which the puddled metal is fallen, is, by preference, made of vertical bars of square iron. It may be constructed, as shown at *a a* of square bars riveted inside two strong hoops of iron, the heads of the rivets being flush on the inside; this forms a receptacle with open top and bottom.

The mould is placed on a low bogie, so that the top of the

mould can be brought under the level of the sill of the back door of the furnace, to receive the puddled metal when pushed through the back door. If the metal has not been sufficiently worked in the puddling furnace, jets of blast from tuyeres suitably placed may be caused to impinge on it during the time it is discharged from the furnace; air thus applied improves the quality of the iron, though it causes more waste. Olefiant gas may be used with advantage when "puddled steel" is being made, as it will prevent the carbon from being burned out during the time the charge is being pushed out of the furnace. The bogie should, after the puddled metal is on it, be removed as quickly as possible to the press, which by preference, should be a hydraulic ram worked by an accumulator.

The arrangement I prefer is shown at 209, 210, 211 and 212. The bogie fits on the top of the ram and is carried upwards by it. Over the mould is a block of cast iron which fits into it, when the ram raises the mould and the block comes in contact with the puddled metal, which is thus pressed into a bloom. On the top of the block, which fits into the mould, is another ram, fixed to which is a crosshead and hooks so arranged that it may be fastened to the hoops surrounding the mould; then by giving an upward motion to the upper ram, the mould is raised up the side of the block, thus leaving the bloom of iron or steel on the bogie, which is then lowered and the bloom taken to a hammer or rolls, or otherwise disposed of. The mould is lowered on a bogie and used as before.

We have given this apparatus and process in full, as it appears to be the best of the kind of which we have any knowledge. But, without any observation of its working, we should say, that certain difficulties appear in the mechanical structure of the shingling apparatus, in the "wrought iron receiver, form, or mould," a powerful pressure upon which would force the iron in between the bars; and in the manner and amount of application of "hydraulic pressure," as some regulation must be adopted to suit the "upsetting" of blooms of different sizes. The principle and object, however, are valuable, and the apparatus indicates what is needed, and it may have practically succeeded in England. A perfect apparatus for shingling by compression would be of great value in the process of wrought iron metallurgy, but in this country it seems, as yet, a desideratum not quite accomplished, although efforts are at present being

made to make practicable this method which we conceive to be the most perfect of all processes of shingling the hot blooms.

General Review and Practical Remarks upon Shingling.

Shingling is the next process after balling, and is performed by the "squeezer." As we have seen in previous pages, the blooms were formerly made by the action of large hammers, and the balls were run under the hammers and watched, so that any defectively puddled part might be expelled, and the rapid and sudden impact of the hammer drove out a larger proportion of silicates than the more modern squeezer of American invention, which rolls and compresses, or than the other plan of somewhat similar nature which simply presses. Another advantage in the hammer was that the blooms were made into cylindrical form, were turned on end and hammered; this was termed "upsetting." This upsetting is considered necessary to the quality of the iron in the bloom. So far as the quality is concerned, it is thought that no method takes the place of hammering. In the item of amount made, however, the modern squeezer is the superior instrument.

The squeezer has almost superseded the hammer, because the first cost is less, and the cost of maintaining power is also less, while the yield is greater. Some are made reciprocating, or double-ended, and the power is obtained by attaching the squeezer either directly to the roughing roller, or by intervention of a "spindle" shaft as recommended by Truran.

The hammer and the anvil are made to work twice the usual quantity of iron before renewal by passing a wrought iron tube through each and inducting water during the process of hammering. The pipes run from the hammerhead along the helve to the fulcrum point where there is least motion, and thence are connected by flexible tubes to the corresponding outside pipes.

A substitution for the common lever squeezer is found in the American invention, consisting of a circular cast-

iron well, eccentrically centred within; being another cylinder whose least departure from the well was equal to the diameter of the bloom formed by tumbling in the ball into the widest departure. The centre cylinder is geared heavily, else it is likely to break, and is lined with teeth or grooves, to catch the ball, and thus by combined rolling and squeezing delivers the bloom at the opposite end of the circular tunnel or canal-way of the squeezer. The only serious objection is found in the fact that no arrangement is made for "upsetting" the blooms, which lessens the good quality of the iron by not properly excluding the cinder and silicates from the ends of the blooms. Other substitutes for the common lever squeezers have been offered, but the features of the difficulty have been about the same in all, namely, cost in construction; turned and carefully fitting parts, rendering it difficult to supply breakages in short times, and heavy demand of power, or incomplete exclusion of cinder with inability to upset the blooms. When all the workmen are good puddlers and the iron well and uniformly worked, the crude iron being of good quality, and the incorporated substances (either from the coal or otherwise) favorable, Truran thinks the advantages are in favor of the modern squeezer, otherwise they are on the side of the common lever, at least for quality. He asserts that "if the crude iron is bad and the puddler an indifferent hand, no squeezer, or other machine ever invented, can improve the quality of his work." No squeezers, therefore, according to Truran, can, by the simple effect of compression, determine the quality of the iron—this was said in view of the assertion on the part of some one that a certain squeezer of his own invention improved the quality of the iron. But it is plain that no such effect could follow except in the sense that the cinder might be more effectually excluded by one machine than by another. "Hammering certainly improves the quality of most bar iron." The rapid compression causes the cinders and silicates to exude while the iron is soft enough to allow of it, otherwise the cinders become wrapped up in the iron. The steam

hammer is superior only where a great range in the force of the hammer is required, but, otherwise, it is of little use, and is obtained at a cost of about five times that of the common mill hammer.

Improvements and Further Remarks on Rolls and Rolling.

The Rolling is the next procedure in order after the blooms have been delivered to the rolls in proper size and shape. It is passed through the larger groove in the roughing rolls and through the lesser, until ready for the finishing rolls, and there passed until delivered a finished puddled bar.

Cinder-plates are used to increase the durability of the necks of rolls, and they consist of thin wrought-iron plates let into a groove near the end of the rolls before these rolls are let down, thus preventing the cinders from getting into the joining of the rolls.

The standards must be strong to resist the pressure in rolling comparatively cold iron plates, and it is recommended that the area (sectional) of the standards to each pair of rolls be not less than 230 inches in the weakest place.

The velocity of the puddling rolls ranges from about 35 to 80 revolutions per minute in Staffordshire and Derbyshire (1855) and in Wales, from 50 to 80, 56 being the speed preferred, except where the metal is very red-short, a higher speed, in that case, causing less waste.

The diameter of the top rolls for squares and bolts is as 61 to 60; this is necessary to throw the iron down on the guides. In the roughing pair the diameter is as 51 to 50.

The speed of rolls varies in different districts, and with the character of the iron; if of a red-short nature, the maximum velocity is necessary. There is a limit however due to the difficulty of seizing the bars by the workmen.

The rolls are generally driven in the same direction; in some cases the rolls have been reversed, and the bar

passed through the succeeding or adjoining groove, but the time lost in reversing, under high rates of revolution, makes it of doubtful economy, especially as complication in the gearing is increased.

A consecutive series of rolls was formerly tried, but a difficulty was found to result in this, that as the bar decreases in sectional area, the velocity of rolls needed to be increased, and the adjustment of time between each roller required such nicety that Mr. Truran and others considered that the advantage was not only doubtful, but a practical impossibility. But in 1867 we find the following:* Messrs. Johnson and nephew, of Manchester, have for some time had in successful operation what they term a "continuous mill" for rolling wire, invented and patented by Mr. George Bedson, the manager of their works. The mill consists of a long series of rollers placed in pairs alternately, horizontally and vertically, each pair of rollers having one groove, through which the wire passes, and is delivered to the next pair of rollers, reduced in section and extended proportionally in length. The gearing of the rollers is arranged so as to give a higher speed to each successive pair of rolls, in order to pass the increasing length of wire through as quickly as it is produced. In the course of the operation there is, of course, one part of the billet within the furnace whilst another part is being coiled up at the other end of the mill in the form of wire.

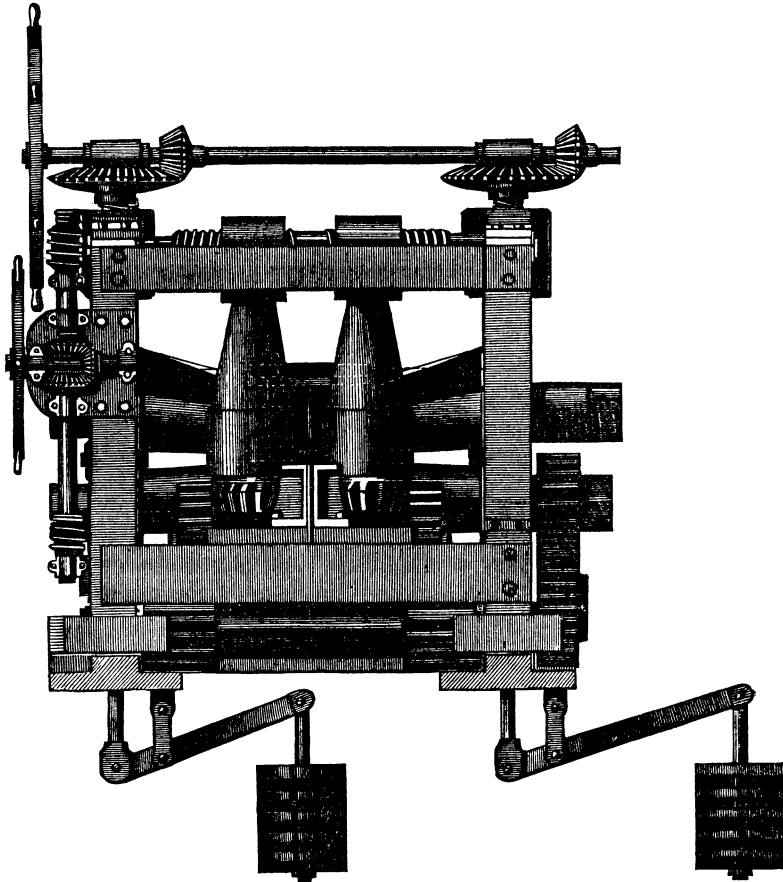
There are seven machines of this kind at the works in question, and their power of production is estimated at about 250 tons of wire per week.

Wagner's Universal Rolling Mill.—We illustrate Mr. Wagner's rolling mill for bars and flats of variable sizes, which has obtained the name for universal mill on account of the facility which it affords for rolling different widths and thicknesses with the same set of rolls. The mill consists of two horizontal rolls, mounted and geared

* Engineering, January 25, 1867.

in the usual way. To these is added a pair of vertical rolls, fixed in bearings which can be traversed on slides in a horizontal direction by means of a pair of right and left screws. The simultaneous movement of the

Fig. 213.

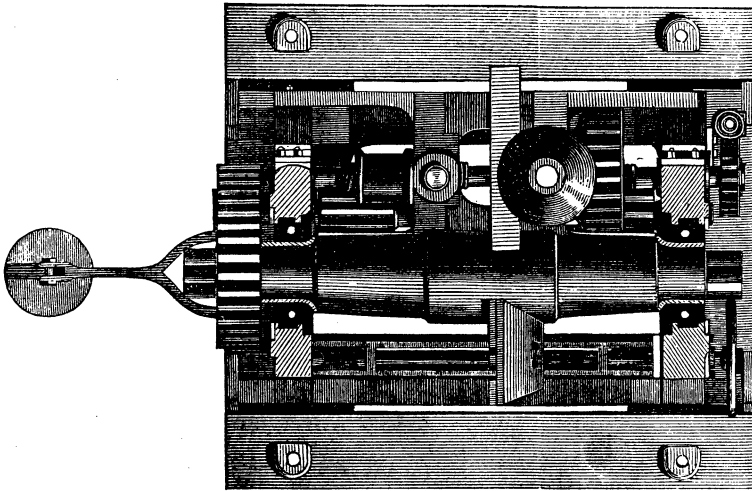


Elevation.

two screws is obtained by a hand-wheel geared to a vertical spindle carrying two worms—Fig. 213. These worms act upon wheels, shown as keyed on to the screw

spindles. By turning these spindles the two vertical are brought closer together or removed from each other, and by these means the width of the bars to be produced in the mill can be fixed at will. The vertical rolls obtain their revolving motion from the driving pinion by

Fig. 214.



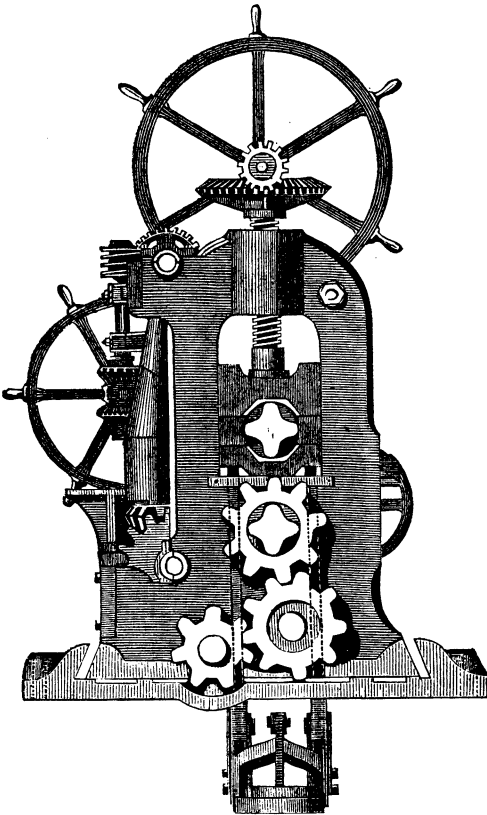
Plan.

means of a pair of bevel wheels geared into other bevel wheels (Figs. 214, 215) which slide on their shaft, following the movements of the vertical rolls. Each of these last-named bevel wheels is cast in one with a spur-wheel gearing into a pinion of sufficient width to allow for its movement in the different positions given to the vertical rolls (Fig. 216). The horizontal top roll is held up in its bearings by a pair of counterweights (Fig. 213), and its distance from the bottom roll is regulated in the usual way by a pair of screws. There are several rolling mills of that kind in operation in Austria, and they have proved very useful and convenient in practice.*

* May 24, 1867, Engineering.

An experiment, in the use of rollers for the same purpose, was made several years ago, at Reading, Pa., under the direction, as we understand, of Mr. Louth, the inventor of the three high rolls. While it did not succeed to satisfaction, we were told by a practical and skilful operator that the only cause was found in

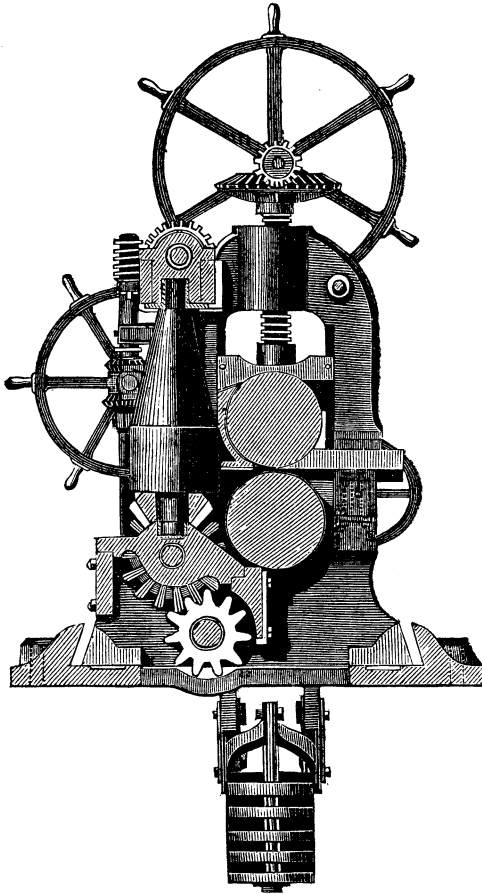
Fig. 215.



Vertical section.

the crudeness of the machinery which had no completeness of finished plan and mechanism, and for this reason alone it was discarded.

Fig. 216.



Vertical section nearer the centre than Fig. 215.

Wrought-iron Screws for Housings.—Mr. Wilhelm, formerly of Phillipsburgh, N. J. sheet-iron rolling-mill, adopted a very efficient method in making his regulating screws of the usual wrought iron, but finishing them with large square faces upon the bolsters over the bearings of the rolls and not in points. These faces are flat and finished with a steel band or cup, which always keeps the screw end fairly square upon the bolsters immediately over the necks of the rolls. Thus, when the iron first

strikes the roll the "bump" is far less likely to injure the regulating screws. In the rolling-mill above referred to these screws have been long in service, and have never given way, nor are they at all battered. In one large rolling-mill, with which we are acquainted, cast-iron screws were used, as it was thought an entirely useless expenditure even to use wrought iron, until upon a sudden bump the threads were stripped and the screw ruined. When the screws are small, convex, or pointed, they are very apt to turn toward one side or another, producing an exceeding strain or leverage in the block or bolster immediately over the roll-neck.

Mending Cast-iron Rolls.—"Burning on" is the phrase used to express a practice lately introduced into some of our foundries, whereby broken rolls and other cast-iron parts of housings, shears, &c., are mended. The practice, as it has been executed in several places, Bethlehem, Pa., Philadelphia, and elsewhere, is to lay the roll in the sand and form a concavity, or hollow, answering to the shape of the part to be "burned on." When everything is ready and the channel, for conducting the molten iron to the spot, ready, the cupola is tapped, and highly heated molten iron allowed to pass into the hollow which is bounded by the bare and clean iron surface sprinkled well with borax, glass, and fine dust charcoal. The molten iron flows until by a rod or other instrument the founder feels that the broken surfaces of the roll are semi-fused to a pasty condition. The flowing is then stopped, the iron allowed to settle and remain in the sand-hole until cool. The iron will then be found to be thoroughly welded, if the operation has been executed skilfully. In England and in France the same operation has been performed frequently during the past thirty-five years, a writer* stating that he performed the operation with perfect success in 1833.

Cold Rolling.—This process is now accepted as a decided improvement upon the best forged iron rods. The

* In the Practical Mechanic's Journal, June 1, 1869.

method is that of powerfully compressing malleable iron in suitably strengthened rollers and housings.

Messrs. Jones & Laughlin, of Pittsburg, Pa., are the American proprietors of patents for cold rolling, which have been so fully indorsed and highly approved by the Messrs. Baldwin & Co., Merrick & Sons, of Philadelphia, and many other practical men, that we do not hesitate in presenting their own views. In a recent communication they remark that they are manufacturing, by a process discovered in their works, "cold-rolled iron." The iron, after being rolled in the ordinary manner, is put through an acid bath for the purpose of cleansing, after which it is rolled cold in rolls of very great strength, by which process the fibre of the iron is compressed and a perfectly smooth, and bright surface given to it. The iron is increased very greatly in strength and elasticity, and is now admitted on all hands to be much superior for shafting, piston rods, &c., to turned iron, and has for many uses taken the place of steel.

Grooved Chill Rolls.—We have read a notice in the Pittsburg Daily Commercial of this invention as made by Messrs. Totten & Co., of Fulton Foundry, Pittsburg, as follows:—

The grooved chill roll is the invention of Mr. Totten, and is a step in advance of anything yet attempted either in America or Europe. The merits of this invention must be apparent to every mill man. Grooved chill rolls, as their name indicates, are rolls cast to shape for rounds, squares, and irregular sizes. Formerly the roll was cast plain, and the grooves cut out afterwards in the lathe.

By making the chill grooved roll to shape, the following points are gained: 1. In the *weight* of the rolls in the rough; no trifling item. 2. In the time consumed in *turning* the rolls; a still more important item. 3. A uniformly hard surface is obtained at the bottom, as well as on the sides of the groove. When a roll is cast plain, and the grooves turned out, the deeper you go into the chill, the *softer* the chill is. As a natural consequence, the object aimed at in chilling the iron is partially defeated, for that portion of the roll relied upon to do the work, viz., the bottom of the groove, is the softest. This difficulty it will readily be seen is wholly overcome by casting the groove. 4. *The entire first cost* of the rolls is saved in a very short time

in dressing. Twelve hundred tons of ordinary rounds, from one to two inches, have been rolled on one pair of these rolls without dressing. One hundred tons, we may add, is considered very fair work for soft rolls. 5. As the rolls do not wear out of shape, uniformity is secured in the size of the iron rolled upon them—a matter becoming daily more important, on account of the urgent demand by railroad companies, machinists and agricultural implement makers for a more uniform size of iron. 6. The iron is more merchantable, being rolled free from scales. The advantages we have enumerated are equally commendable to manufacturers of steel.

Mr. Totten has succeeded in casting, as we understand, for Messrs. Mathews & Moore, of Philadelphia, for the steel works at Lewistown, Pa., rolls of the following dimensions:—

Diameter, thirty and a half inches; length of body, ninety-six inches. Fifteen and a half tons of metal were required to make each casting.

Mr. Hewitt, in his report upon the Paris Universal Exposition of 1867, speaks of rolls at Petin, Gaudet & Co.'s works, which he saw, of the diameter three feet six inches, and of those at John Brown & Co., Sheffield, rolling plate iron six feet wide, requiring rolls three feet in "size," by which latter word we suppose is meant diameter.

Mr. Thomas D. Lewis, of Knoxville Iron Co., Knoxville, Tenn., however, succeeded in 1846 in casting grooved chill rolls at Danville, Pa. Mr. Lewis writes us that he made them in 1845 and 1846, and thinks he was the first to cast "sweep grooved rolls," and in 1863 he renewed the machinery, and cast both merchant and rail chill groove rolls. At present we know of no rolls superior to those of the Fulton Foundry, of which Mr. Robert C. Totten is the principal manager.

Puddling-Ball Rolls.—These rolls are intended to do away with the necessity of squeezers altogether. We have seen the puddled balls taken directly from the puddling furnace, and carried to a kind of muck bar rolls, and there rolled out ready for the finishing rolls. Mr. Robert C. Totten, of the firm referred to above, in whose inventive and indomitable energy we have con-

fidence enough to believe that he will succeed in making the rolls perfect, has attempted to complete this invention of Mr. Jacob Reese, of Pittsburg. It is automatic in its invention, and does away with all labor in the production of muck bar, as it takes the puddled ball directly from the boiling furnace and converts it into muck bar. Although we do not feel, that, practically speaking, it is quite yet a success, it has sufficiently progressed to show that this desideratum will certainly be reached, and, for many reasons, it will be a great improvement.

CHAPTER V.

REHEATING FURNACES, SHEARING, PILING, &c.

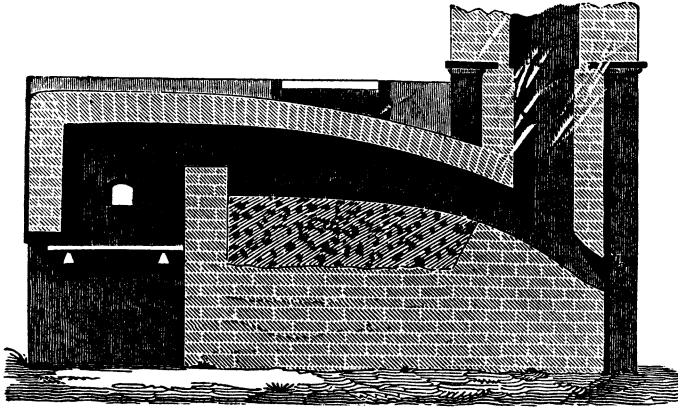
THE reheating furnace is intended to perform the work which the puddling furnace was not able to complete, in that the iron of the ball in passing through the various processes of shingling and rolling into the first rough, or muck bar, had become too cold to be further shaped neatly and smoothly, and needed another heat for further rolling or welding, after being cut into short pieces and piled together. Such being the object of the reheating furnace, we shall describe it before proceeding.

Reheating Furnaces.

[Reheating furnaces are those which serve to give a welding heat to the iron. In these furnaces, either piles of flat rough bars, or single billets are heated, scraps are welded, and the first heat to sheet iron is given. A reheating furnace may be a little longer, but it differs but little from a puddling furnace. The same kind of chimney, with the same dimensions, is employed, and the outward form of the furnace is the same as that of the puddling apparatus. Fig. 217 exhibits a reheating fur-

nace, with the exception of the chimney, which it is not necessary to represent. The whole interior, with the

Fig. 217.



Section of a reheating furnace.

exception of the hearth *a*, is made of fire-brick. The hearth is constructed of sand. For this purpose, a purely silicious sand is required; the coarser the better. Pebbles of about half an inch in size are the very best article we can select. If no sand of sufficiently good quality can be conveniently obtained, white river-pebbles, or white sandstones, burnt and pounded into a coarse sand, will answer for making the bottom of the hearth. The hearth slopes very much towards the flue; and this inclination tends to keep it dry and hard. Provided the sand is not carried off by the flowing cinder, the slope cannot be excessive. The iron wasted in reheating is combined with the silex of the hearth, and forms a very fusible cinder, which flows off through the opening *b*, at which there is a small fire to keep the cinder liquid. The sand bottom, from six to twelve inches thick, rests on fire-brick. After two or three heats, it is generally injured by the melting cinder, when some additional sand is required to fill up the cavities that are made. The height of the fire-brick arch, or its distance from the sand bottom, is seldom more than twelve inches; and,

for common purposes, it can be reduced to eight inches, without injurious results.

a. In these furnaces, the grate is very large in proportion to the size of the hearth ; and, with respect to the rules laid down for the construction of puddling furnaces, extremely large. The grate is frequently as large as the hearth, and seldom of less size than half its area. The mean for general practical application lies between these dimensions. Nevertheless, we should be guided by local circumstances, for a size that would be appropriate in one case would not be suitable in another. The rules which govern us in proportioning the size of the grate and hearth depend, as in the case of the puddling furnace, upon the quality of fuel we employ. That is to say, a larger grate is required for anthracite than for bituminous coal, and a larger one for the latter than for wood. We should also be influenced by considerations of economy. A large grate produces a greater yield than a small one, provided the rollers take the iron fast. A large grate works faster than a small one, and consumes less fuel. Hence, the advantages appear to be in favor of the former. But, in cases of slow work, and iron of small dimensions, the reverse is the fact. The hearth of a reheating furnace ought never to be longer than five feet, and it may, with advantage, be reduced to three or three and a half feet. A long hearth will produce but an imperfect welding heat; it works too cold either at the bridge or at the flue. The flue should be as wide as the hearth, and contract gradually towards the chimney. This produces a uniform heat throughout the hearth. Where a hearth is to be made larger for special purposes, such as for heating rail piles, or any other heavy piles, it is more advantageous to extend its breadth than its length. The width of the furnace is generally five feet, but these dimensions may be extended to eight and even more feet, without inconvenience.

b. The quantity of iron reheated in a good furnace depends on circumstances. Much depends on the character of the mill, and upon the kind of iron we design to produce. A good furnace will produce in twenty-

four hours, from eight to ten tons of iron employed for coarse bars and hoops, and an equal amount of railroad and other heavy iron. But it will not produce more than from two to four tons of iron designed for small rods, hoops, and wire. Where small iron requiring no welding heat is made from mill bars, large furnaces may be employed. By this means, we may obtain twice the amount just stated, if such an extension is deemed advantageous. By so managing the furnace as to make a heat in the shortest possible time, we shall, in all instances, arrive at the most favorable results. The time required will, of course, vary according to the size of the iron. Still, it is evident that both iron and fuel will be economized in proportion to the shortness of the time consumed in welding a given amount of iron. Another good rule is, to work slowly from the commencement of each heat, to charge the exact amount of fuel required to finish a heat, to keep the temperature as long as possible below a welding heat, and then, after suddenly raising the temperature to that standard, to draw as fast as the rollers will receive the iron. Small charges of iron generally produce a better yield than large charges, but consume more fuel. Where fuel is cheap, and iron expensive, it is better to charge only a small amount of iron at a time, and to make a proportionate increase in the number of heats.

c. Reheating furnaces are employed for welding wrought iron scraps. For this purpose, a variation in the height of the arch from the bottom of the furnace, and in the form of the hearth, is required. The height of the arch, in such cases, is generally from eighteen to twenty inches; and the hearth is somewhat more level than usual. In some establishments, scraps are assorted, and put up in bundles of from forty to fifty pounds each. Due care is taken to have the pieces of iron in each bundle of equal size; that is, sheet iron and bar iron scraps should not be bound up together. These bundles, well secured by binders, after receiving a welding heat, are either shingled or rolled. This course is also pursued at charcoal forge fires. At these fires, the bundles

are reheated singly, and drawn out into bar iron, according to the method commonly practised. At some places, another method is pursued. This consists in charging the reheating furnace with loose scraps, applying to them a welding heat, and forming balls in the same manner that they are formed in the puddling furnace. These balls are brought to the T hammer, or squeezer, formed into blooms, and roughened down into bars, as puddled iron. Scraps make a very fine bar iron, particularly in the charcoal fire, and such iron is highly valued by the blacksmith. Where good iron is generally manufactured, there is no special demand for scrap iron rods. Iron made from these scraps cannot be cheap; therefore, there is no advantage in seeking to make specific qualities of it. Where scraps can be bought at reasonable prices, the most profitable way of using them is to cut them into small pieces, about the size of one's hand, and to charge the puddling furnace with them. This should be done at the time the iron in the furnace is so far worked as to be nearly ready for balling. From fifty to seventy-five pounds may be thrown in at one time. By this application, the puddled iron, instead of being injured, will be benefited. Thus, large quantities of scraps may be worked to advantage. Wages at the puddling furnace are not only economized, but the excessive waste of iron in the reheating furnace and the forge fire is obviated. The cinder of the puddling furnace protects the scrap iron.]

The iron slabs or bars are introduced in piles the sizes of which are regulated by the order—the sectional area of 3 in. square being small, to 12 in. square large, with a length of 3 to 4½ ft. 3½ ft. long, 7 in. wide, and 8 in. high, is a common English railroad iron size. Of these, 4 may be charged at a heat upon an instrument termed the “peeler,” slid carefully in and watched after heating, so that a uniform welding heat is obtained. After the heat is up, the cinder or earthy matter in the bars melts, flows over the bars and protects the iron from oxidization for a short time; but if the heat is kept up too long, oxidization takes place, more or less injuring the

operation and the quality of the resulting bar, so far as tenacity and homogeneousness are concerned.

The loss of weight is dependent upon the puddler and the quality of the iron. When both are fair, the loss should not much exceed 80 lbs. per ton on the large piles, on some iron as high as 210 lbs., and may be higher; but sound (*i. e.*, welded) bar iron may be produced with *only* this loss. (Truran.)

Heating Ovens.

[Iron which is sufficiently soft and malleable to be wrought into any shape by the hammer or roller does require a welding heat. For such iron, a cherry-red heat will suffice. This heat is produced by ovens or stoves. In these ovens, all sheet iron and rods which require an extra polish, or tempering, are heated. Charcoal billets, from the forge, are also heated in them, to be rolled into rod iron of small size.

a. These ovens may be heated by a variety of methods, and with almost any kind of fuel; still, every caution is requisite to prevent, as far as possible, the access of free oxygen and steam, for both steam and oxygen occasion waste of iron. For these reasons, our statement must be received with some qualification. Wood, peat, and brown coal are, so far as their capacity for generating heat is concerned, an excellent fuel; but, unless they are very dry, the steam generated from their hygroscopic water will oxidize, and thus destroy an amount of iron whose expense will not be counterbalanced by the entire profits derived from the fuel employed. Therefore, instead of using the raw material, it will be found advantageous to use only the charcoal derived from charring it.

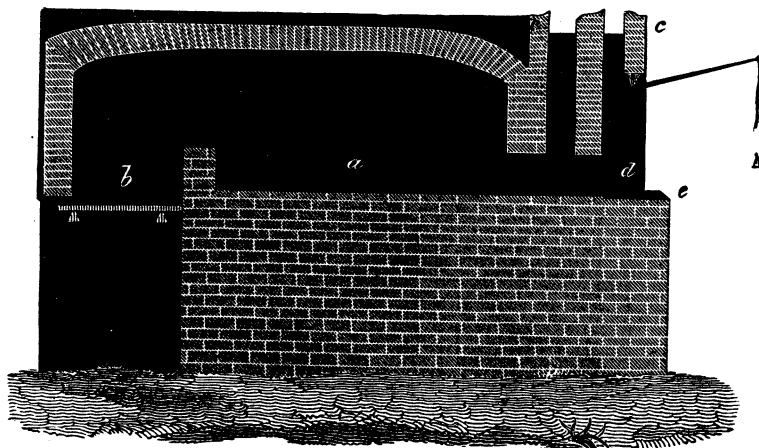
The same objections which apply against any fuel containing water—which of course excludes the use of all kinds of heating, reheating, and puddling furnaces—apply against waste flame, for this contains a large amount of steam, or free oxygen.

b. The ancient form of a heating oven was that of a

common bake oven, with this difference, that the bottom was formed of iron bars. Upon these bars, placed in the form of a grate, coal from ten to fifteen inches in depth was laid. The iron was placed upon the coal, after the oven was heated. In some establishments, such ovens are still employed. It is evident that a portion of the iron in contact with the fuel—particularly raw fuel, such as peat, brown coal, and bituminous and anthracite coal—must be wasted. The only instance in which such an arrangement may be considered profitable is where wood charcoal is employed. Even the best coke or peat coal is not sufficiently pure to guarantee success. Stone-coal, coke, and peat or turf are never free from sulphur, and this sulphur will of course combine with the iron. A waste of iron is thus occasioned exactly proportionate to the amount of sulphur the fuel contains. In addition to this, sulphur blackens the metal, which, in the case of sheet iron and nail plates, gives rise to very disagreeable consequences. Fuel burned in this way, even though spread in a high column upon the grate, never combines with all the oxygen which passes through the coal; the result is a waste of iron. Therefore, there is every reason why such ovens are not serviceable.

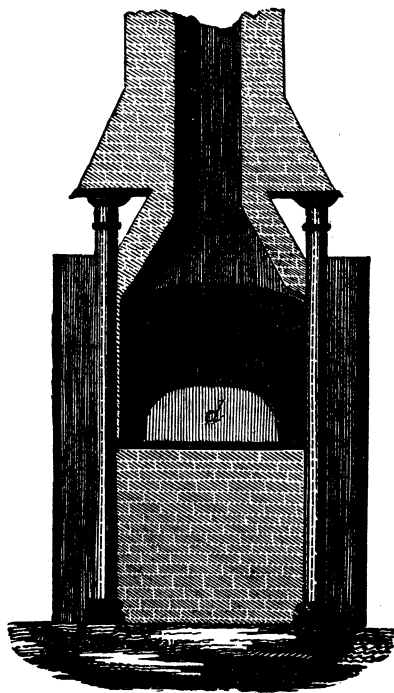
c. Heating over of a superior kind are at present constructed on the principle of the reverberatory furnace. In these, the fuel and iron are properly separated, and all contact between them obviated. Fig. 218 represents a vertical section of a heating oven for sheet iron; *a* is the hearth, *b* the fire grate, and *c* the chimney. The height of the furnace is often thirty inches. The object of this is partly to prevent the contact of the flame and iron, but principally to gain room for setting the sheet edgewise; they are thus set on both sides of the furnace; besides, in the middle of the hearth, sufficient room is left for laying a sheet or two flatwise. *d* is a cast-iron plate, forming a sliding door. The chimney has two flues, the one inside, the other outside of the oven. Its draft is weak, and the smoke or flame frequently issues from the mouth, in which case it is carried off by the

Fig. 218.



Heating oven for sheet iron.

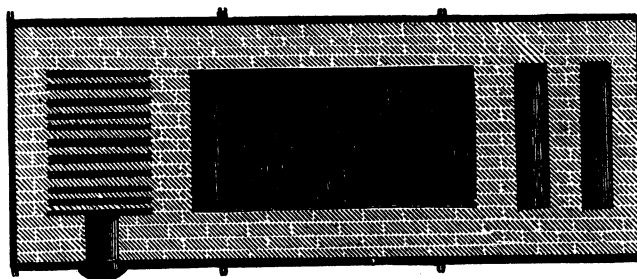
Fig. 219.



Front elevation of a heating oven.

second or outside flue. Fig. 219 represents a vertical section across the furnace and the flues ; and Fig. 220 a ground-plan of the furnace, hearth, and fireplace. The cast iron plate *e* is here shown more distinctly. Its

Fig. 220.



Ground-plan of heating oven.

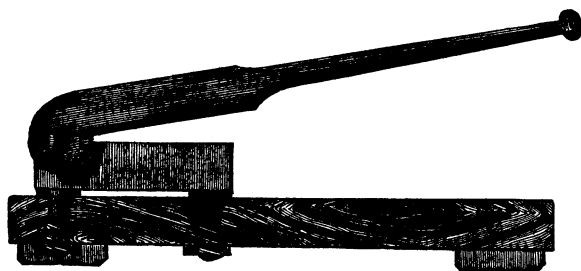
object is to protect the bricks or stones from the destructive agency of the tongs and iron. Like puddling and reheating furnaces, these ovens are built of fire-bricks, inclosed with cast-iron plates, and preserved from the effects of expansion and contraction by wrought-iron cross binders. A slight variation from the form of the oven we have described, occasioned as well by individual taste as by locality, is sometimes observed ; still, the one we have presented is the one generally employed for the manufacture of sheet iron. If it is desirable that the surface of the iron should be kept very clean, the fire bridge and the inside flue may be raised ; but, in all such cases, pure fuel is our safest reliance.

Shearing.

Movable hand-shears are the shears required in a mill for cutting small rod and hoop iron, and *force-shears* connected with a waterwheel or steam-engine, for cutting common bar, rough bar, and sheet iron. The first are small lever shears, fastened upon a two inch plank, as represented in Fig. 221. The length of the whole is about two feet or thirty inches. The shears are placed

at each end of a pile where small bar or hoops are deposited. The boys, who catch behind the rollers, cut off the bad ends, before a rod or hoop is laid down.

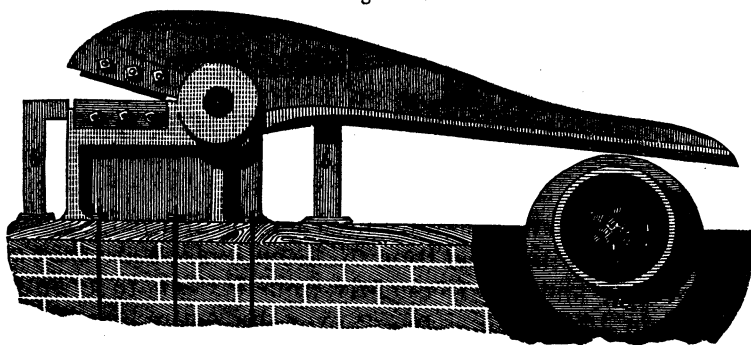
Fig. 221.



Portable hand-shear.

c. Fig. 222 represents *the common force-shear*. It is a powerful cast-iron lever, varying, according to locality

Fig. 222.

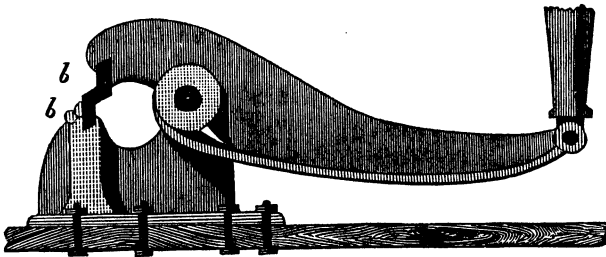


Shear moved by an eccentric.

and purpose, from seven to twelve feet in length. The eccentric *a* is generally fastened upon the main shaft, or, if such is not accessible, upon any other strong and well-supported shaft. The foundation must be very firm, and not inferior in solidity to the roller trains. The steel blades are made of good shear or cast steel, tightly fitted into the cast-iron lever and standard, and screwed on with screw bolts. For the cutting of heavy bar and

rough bar, the standard block is generally placed very low, about a foot above ground; but for cutting common bar and sheet iron, it is raised from two feet to thirty inches above ground. If sheet iron is principally brought to the shears, an iron frame *b, b*, as high as the lower cutter, is to be fastened to the standard. Upon this frame, the sheet is moved. In working sheet iron, shears of this construction are attended with some disadvantage. The acute angle at the points, and the obtuse angle close to the fulcrum which they form, in addition to the difficulty of adjusting them accurately, make them somewhat objectionable. To obviate these disadvantages, various plans have been devised, of which the following, Fig. 223, appears to be the most practicable.

Fig. 223.



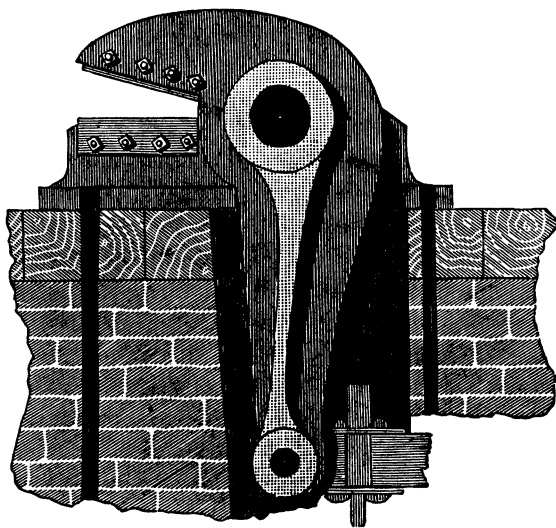
Shear moved by a crank.

These shears are generally used for cutting nail plates, and for trimming sheet iron. The cutters *b, b* are shown in section, and are frequently from sixteen to twenty inches in length, so as to cut over the entire breadth of a sheet; the same length is required where sheet iron is used for making nails. In case small nail plates are used, shorter cutters can be employed. The lower or fixed cutter is horizontal, but the upper is screwed to the cast-iron lever in such a manner as to form an angle with the lower cutter seldom greater than fifteen degrees. The motion of the lever can be produced by an eccentric, as in Fig. 222, or by a crank, as in the present case.

It frequently happens that shears are wanted where

we cannot reach directly to an eccentric with a lever, nor in a short way with a crank. In such cases, a crank motion from some shaft is conducted below ground to the desired point by means of an iron connecting rod. This arrangement, which may be modified according to circumstances, is exhibited by Fig. 224. The tail may be turned above or below ground, forward or back; but

Fig. 224.

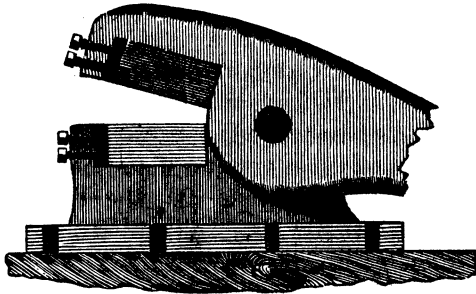


Shear moved by a crank.

care should be taken that the connecting rod is always on the pull side, as shown in the drawing, for a long connecting rod is not adapted to push the lever. This arrangement—in which the shears are directly connected with the elementary power—is necessary where heavy bar iron and boiler-plate are to be cut, for these require a strong foundation. Portable shears, with their own independent flywheel, propelled by means of a belt and pulley, are preferable for light iron, sheet iron, or nail plates. Bar iron more than two inches square cannot be conveniently cut by shears; like railroad iron, this is to be trimmed by circular saws.

d. The method of fastening the steel cutters to the castings by means of screw bolts passing through the steel blades, is exposed to several serious objections. In this way, the blades are weakened, and screws and cutters frequently broken. Strong blades would meet the emergency, but cannot be successfully fastened by screw bolts. If designed for heavy work, the cutter should be very strong, and formed of a solid piece of steel, from an inch and a quarter to an inch and a half thick, four inches wide, and eight inches long. By fitting such a piece of steel carefully into the cast iron, and holding it by means of steel screw bolts, as represented by Fig. 225, it may be conveniently and securely fastened.]

Fig. 225.



Screwing in the cutters.

Cold shearing of bars is done with one advantage, namely, retaining a uniform length, unaffected by heat at different temperatures. Powerful shears with eccentric cam descend vertically with power sufficient to cut bars 5 inches square with greatest facility.

The *use of saws* in cutting bolts is made important when a square end is desirable, and a notch in the shears when flattening of the rods cut is to be avoided; these notches are semi-circular and triangular, according to the shape of the rod or bar received into the jaws of the shears. The steel edges or knives have to be changed every few hours from softening. The saws may be driven to 1300 revolutions per minute without disad-

vantage. Sometimes a single bench with a saw at either end cuts off the bar at right lengths at once. When great nicety in the length is requisite allowance must be made for contracting on cooling.

If the benches work freely and steadily, and the saws are truly set, revolving at a high speed, the end of rail cut will be smooth as though cut with a file, otherwise it must be smoothed by file. Steel saws will cut from 600 to 700 bars, and work from 12 to 24 hours, according to cuts made, and then must be resharpened, which in some places is beautifully done by punching out a triangular piece by a powerful punch. The saw may be kept cool and free from loss of temper by revolving in a bosh of cool water at the bottom. (Truran.) Saws are used also for cutting in steely iron. (See Homogeneous Metal under STEEL.)

Piling is important in respect to the arrangement, the weight, the nature and size of the pieces, also as respects the object for which the future bar is to be used. In flange irons, great care has to be exercised, as the strength of the body is such that, unless care and skill are used, the body will tear off the flange when finished in the finishing rolls. A rail pile for common qualities is generally piled (Truran) thus: a No. 2 iron, *i. e.*, iron heated after refining (the 2d time) 6 or 7 inches wide by 1 inch thick, is placed at the bottom; upon this 18 or 20 pieces of puddled iron 3 to $3\frac{1}{2}$ inches wide by $\frac{5}{8}$ thick, are placed and capped by a piece of No. 2, again of the same size as the first. If it is to be a flange bar, two square bars of soft iron are placed upon the base, No. 2 iron for the flanges. Hematite, or refinery cinder, is carefully avoided in the iron used for this purpose, and overheating is carefully avoided.

A *dense fibrous* character is given to the bars by piling in short and thick sets, and thus rolling out more extendedly; but difficulty is found in heating the centre bars to welding heat. So, also, in the form of radiated bars, or bars placed longitudinally around a centre bar, and thus rolled, as for piston rods. In several cases where the rods broke, it has been found that the centre

rod was not properly welded to the others. In scrap iron, fagotted, hammering before it is rolled greatly improves "the quality" of the iron. Cross piling also greatly improves the iron in respect to its ability to bear a strain. Boiler plate invariably, if made from best iron, is rolled with alternate layers laid crosswise. A cheaper way is adopted in Staffordshire, of rolling two blooms together after slabbing them in the rollers—yet this is not so good as No. 2 iron, and it should never be less refined than No. 3. Truran is of opinion that piling is of advantage in railway bars, in proportion to the material and manner of piling; and an attention to the manner of piling, crossing the piles, caused the iron in fracture to appear much as cast steel; and a particular kind of piling caused one set of bars to be soft and fibrous on one side, and crystalline on the other.

The fibrous character of iron is heightened by rolling in the grooves, and, again, by piling and rolling again. "If the bloom from the shingle is slabbed down between cylindrical rolls, varying the direction each time, there will be no fibre, but a scaly appearance. Reheating and rolling into a thin plate, the fibre is still absent, but the scale is finer. This cross-piling and rolling increase the tenacity and hardness. But the fibre is produced while the iron is in a plastic condition. Rolling, hammering, or other pressure, when cold, injures the fibre of iron." (Truran.) The advantage in rolling long bars is in the saving of the crop ends.

Mr. Benjamin Haywood, Superintendent of Pottsville, Pa., Rolling Mill, takes great pains to separate the members of the rail pile, so that the heat may thoroughly permeate the pile. His pile is generally composed of 13 pieces, the top and two bottom of one piece 7 inches wide, the rest each of two pieces—the top of best reheated iron, and the bottom of best puddled iron, seven-eighths thick. But the greatest care is taken in the welding. Some of Mr. Heywood's rails have been put to a very trying test, and have shown a remarkable solidity and homogeneousness. Mr. Fritz, of Bethlehem, Pa., Rolling Mill, as we have been told,

makes a very efficient use of red-short iron in certain parts of the pile.

In Austria, a remarkably tough rail and a hard one is formed from piles containing not only flats, but irregular pieces, whose cross section is like rails of various patterns. Some of these piles contain as many as twenty-seven pieces. After all, the greatest advantage is to be gained from thorough welding.

The average yield of puddled bars in two furnaces (large) of Monkland, Dandyran, was one ton to 23 cwt. 3 qrs. 19 lbs. of pigs. This was from carbonaceous ores and the worst of those irons converted. But with good coal and a fair pig and average workmen, it is set down that very favorable results make the average of $21\frac{1}{4}$ cwt. pigs to the ton of bars produced.

From refined metal the yield of bars requires somewhat less of refined metal, say $20\frac{1}{4}$ cwt. of refined to the ton of bars, but the difference between the yield of bars from crude and from refined, is not much.

The following table exhibits both the form of keeping accounts and the facts as associated with the work of one of our most successful American rolling mills, the coal being anthracite.

	STOCKS USED.		PRODUCT.		WASTE.	REMARKS.	
	COAL.	PIG IRON.	PUDDLE BAR.				
	Tons.	Tons.	Tons.	Cwt.			
	Puddle Mill No. 1	319	329	296			0
	" " " 2	226	196	164			0
Totals	545	525	460	0			
	COAL.		RAILS.				
	Tons.		Tons.	Cwt.			
Rail Mill	413		480	13			

Consumption of coal varies in the same degree. With a very flaming bituminous coal and good workmen, 14 cwts. to the ton of puddled bars is the average, with less inflammable coal 18 cwts. and with these coals edging upon the anthracite, as high as 22 cwts. per ton. Good puddlers will make a difference, saving from 4 to 5 cwts. per ton. In double furnaces about $\frac{1}{4}$ of coal is saved, where the workmen work together. An improvement, whereby some saving in coal was effected, was made by inclosing the ash pit and passing hot air both below and above the grate, thus consuming the gas more effectually. but where the irons used were harder to melt, the loss in iron was greater than the saving in coal.

The Cost of Making Rails.

Mr. Morrell, of Wood, Morrell & Co., of the Cambria Iron Works, at Johnstown, Pennsylvania, sent *Engineering* a statement of the cost of making rails, per ton, at his works, the items having been taken from his own pay-rolls in October, 1866,* which was as follows:—

(Gold is taken at \$4.84 for the English pound, which, in American currency, was \$6.45, premium being 33 $\frac{1}{3}$ per cent. at the time the estimates were made.)

	American Currency.	English gold and silver.		
		£	s.	d.
Pig iron, per ton	\$43 00	6	13	2 $\frac{1}{2}$
Waste in puddling, 12 per cent.	5 16	0	16	0
Piling, breaking, and delivering metal to puddlers	24	0	0	9
Removing ashes, cinders, &c.	24	0	0	9
Puddling	6 83	1	1	2
Repairs, &c. of puddling furnaces	1 00	0	3	1
Squeezing puddle blooms and rolling puddle bars	1 96	0	6	1
Repairs of puddle rolls, engines, &c.	15	0	0	5 $\frac{1}{2}$
Coal per ton of puddle bars	1 51	0	4	8
Reworking tops and bottoms of rails	75	0	2	4
Reworking rail ends and defective rails	64	0	2	0
Piling, heating, and rolling rails	2 05	0	6	5
Straightening and finishing	86	0	2	8
Repairs of engines, rolls, &c. at rail and top and bot- tom mill	58	0	1	9 $\frac{1}{2}$
Repairs of furnaces for rail and top and bottom mill	15	0	0	5 $\frac{1}{2}$
Coal for reheating, per ton of rails	1 25	0	3	10 $\frac{1}{2}$
Brick masons	23	0	0	8 $\frac{1}{2}$

* *Engineering*, March 15, 1867, p. 236.

REHEATING FURNACES, SHEARING, PILING, ETC. 841

	American currency.	English gold and silver.	£	s.	d.
Bar iron, steel castings, smith-work, machine-work, boiler repairs, fire-brick, kindling wood, timber, car- penter's work, fire-clay, &c. &c.	2 50	0 7 9			
Carter's wages	50	0 1 6½			
Oil, grease, brass, Babbett's metal, belting, packing, &c.	38	0 1 2			
Handling rails, and miscellaneous labor	43	0 1 4			
Waste of iron from puddle bars to rails, 15 per cent. on 60 dollars (value of puddle bars per ton)	9 00	1 7 11			
Insurance, clerk's, managers, and general office ex- penses	1 00	0 3 1			
Total per ton	80 41	12 9 2½			

The editor of *Engineering* says, that English manu-
facturers wonder how American railway companies can
afford to pay £12 9s. 2½d., when rails of equal quality
may be had in Staffordshire or Middlesboro' at from £5
15s. to £6 15s. per ton. One pound per ton is freight
cost to New York, and duty payable in gold, £3 4s. 9½d.
per ton added. With commission, &c., at 3s. 6½d. per
ton, the total cost of importation was \$62.39, currency,
(at the time specified), or £9 13s. 4d. in gold. Without
this duty, amounting to 60 per cent. upon the English
market price, American iron masters could never compete
at all.

Cost of Rail Making in the Cleveland District, October, 1866.

	£	s.	d.
26½ cwt. of pigs	3	5	0
52 " of coal	0	17	0
Fettling materials for repair of furnaces, stoves, oil &c.	0	8	0
Puddling per ton of puddle bars	10s.	6d.	
Shingling	1	8	
Rolling puddle bars	1	2	
Repairing puddling furnaces	0	6	
Wheeling, fettling, tipping, &c.	1	4	
Main hammer and engine drivers, &c.	1	0	
Add ¼ for waste of puddle bars to rail	16	2	
	4	0½	
Mill furnacing and ball furnacing	1	0	2½
Rolling	4	6	
Cutting down	2	6	
Sawing, straightening, and punching	1	0	
Repairing-mill furnaces	2	0	
Wages in coal tipping, ash wheeling, sand wheeling, helpers, chargers, loaders, smiths, fitters, joiners, stablemen, general laborers, weighers	0	6	
	7	3½	

Total £6 8s., and beyond these are the costs of management, clerks, agents, discounts, commissions, risks, wear and tear, rates, water, &c. In the Welsh district the prime cost is less.

Tools.

[The tools required in a rolling-mill are of some importance, and absorb considerable means in their outfit and repair. The principal tools are tongs, which, in an extensive establishment, are very numerous. A set of tongs belongs to each reheating furnace, comprising long tongs for the catching of small billets, and tongs for heavy piles. A set is placed before and behind each set of rollers, which are shorter than those at the reheating furnace. A different kind from the above, from three to four feet long, belong to the heating ovens, and short, narrow tongs are necessary at the sheet rollers. The tongs of a rolling mill, and the manner in which they are kept, show in a great measure the character of the establishment. Light, well-made tongs, calculated to answer their different purposes as well as possible, kept in good repair, and in sufficient number, indicate a well-managed mill. Clumsy, heavy tongs, roughly made, in bad repair and in insufficient number, are a sure sign that something is wrong in the management of the mill; and, by close investigation, we shall find similar deficiencies in all the other departments of the establishment. To make good and light tongs, sound and strong iron is required. Strong shear steel is the best material for making light and elegant tools. But where the steel is short, it is advisable to pile steel and good charcoal iron alternately. The resulting metal, drawn into bars, will make a kind of Damascus steel, of great cohesiveness, from which light tongs of the most elegant form may be wrought. A number of hammers, sledges, and wrenches are also required. At each reheating furnace, there must be a water trough, supplied constantly by a current of cold water, for the purpose of cooling the tools. From three to four hooks, five or six feet long, and

lighter than those at the puddling furnaces, belong to a reheating furnace; also a couple of pointed bars for turning the piles. Piles composed of bars are to be turned as soon as the heat of the furnace is sufficiently strong to make them adhere.

Small rod iron, hoops, and some kind of wire, are put up in bundles of fifty or one hundred pounds weight each, on a bench constructed for the purpose. The rods of small iron are first weighed; a parcel of the desired weight is then put upon the bench, into iron standards, and these tied together by iron hoops. The bench is a table eighteen or twenty feet long, two or three feet wide, and made of plank three inches thick. Wrought iron stands, in the form of a V, are fastened at such distances from each other as to suit the convenience of the binders, say from two to four feet. To one leg of the stand, a small lever about a foot or a foot and a half long is fastened; it is pressed upon the bundle of iron, forced down and locked. A binder of small square or round iron is then fastened in that place. These binders are generally tied when heated; but, in many establishments, they are tied cold around the bundle. Generally three binders, seldom four, are fastened to one bundle. Hoops, and small, well-polished rod iron ought to be handled by the workmen in gloves, particularly in summer; for clean iron has a fine appearance.

General Remarks.

a. Where the country is settled and densely populated, there is generally a large demand for iron, and competition and large establishments have so reduced its price that a profitable employment of Catalan fires cannot be expected. But, in less settled countries, where wrought iron for farming purposes is in demand, and where rich ores are accessible, the Catalan forge is profitable from the fact that but a small capital is required to start it. The machinery can be made very cheaply, if a water power is at our disposal; and even a steam engine costs but little. A hammer 150 or 200 pounds in weight is

sufficient to do a great deal of work, at least work for two fires, and will draw, every week, from five to six tons of iron, if the rods are not smaller than horseshoe bars or wagon-tires. From good ore, the iron made in the Catalan forge is preferable, for agricultural purposes, to any other kind of iron. The expenses of erecting this forge cannot be stated with precision; but they depend on locality, industry, and the kind of iron wanted. A Catalan forge may be put in operation at an expense of 500 dollars; but ten times that amount may be laid out to advantage. As the main body of materials required are timber and stones, its erection, in a new country, where timber is abundant, cannot cost a great deal. Hardly any stock of coal or ore is needed; and the ore and coal worked to-day may be turned into iron and cash to-morrow.

b. Very little bar iron is drawn in the charcoal forges, and that which is made is horseshoe, tire, or heavy bar and pattern iron. For all these purposes, cast-iron hammers and anvils, if made of good cast metal, are sufficiently hard and smooth. But if we want to draw fine iron or steel, wrought-iron hammers and anvils, furnished with well-hardened and polished steel faces, are necessary. It is difficult to weld steel to a large piece of iron, without spoiling the steel; it is, therefore, more profitable to insert the steel, in a separate piece, into a groove made in the hammer face, and in the anvil, and to fasten it by means of wedges. Such a piece may be of the best kind of cast steel, and very highly polished, without running the risk of breakage or loss of lustre. The more strokes a hammer makes in a minute, and the lighter the hammer and the more polished the faces, the greater lustre the surface of the rod will show. The exclusion of oxygen from the heating-oven, and water from the anvil, will impart a uniform blue, or dark violet color to the iron. If we want a fine, polished surface, and a good color, the iron must be heated in an oven, upon charcoal, by a low heat, with the utmost exclusion possible of atmospheric air; the coals, burning in a very suffocated fire, will form only

carbonic oxide; the surface of the iron or steel will thus be prevented from oxidizing.

c. In rolling-mills, iron is rolled and drawn to one-fourth of an inch in diameter, whether round or square. Smaller iron is drawn from the above in the wire mills, by passing the rods through holes made in steel plates. Hoop iron is made as small as five-eighths of an inch wide, and one thirty-sixth of an inch thick. In former pages, we have spoken of the quality of iron required to manufacture small iron to advantage; it is only necessary to remark here, that the rollers and reheating furnaces are to work in such perfect harmony, that the least loss of time in taking out the iron from the fire must be obviated. The quantity of the iron not only suffers, but its quality also, if it is too long exposed to the influence of the flame in the reheating furnace. The iron loses, with its carbon, its strength and lustre; it looks dull, and is more or less rotten or cold-short. We would repeat here the remark formerly made, that, if we want the iron to have finely polished surfaces, we must employ hard and well-polished rollers; for the lustre of the manufactured article cannot be greater than the polish of the rollers from which it receives its impression. A train of five-inch rollers ought to make, in a week, from twenty to twenty-five tons of small iron, with a loss of not more than ten per cent. of iron if made directly from rough billets, and of not more than seven or eight per cent. if rolled from merchant bars. The amount of coal consumed, whether anthracite or bituminous, does not exceed half a ton to each ton of iron.

d. Iron of first rate quality is not required for the manufacture of hoop and small rod iron; any cold-short iron will answer. For particular purposes, such as the making of small chain rods, a fine-grained, yet cold-short, iron is preferable, unless we design the rods to be fibrous. Cold-short iron is to be preferred for small articles made by the blacksmith, on account of its welding properties. We do not mean to say that an excess of silicon or phosphorus is not hurtful to small iron; on the contrary, we wish it to be understood that such matter is very

injurious. Iron containing a small amount of silicon or phosphorus, and sufficient carbon to make it cold-short, is the most profitable for the manufacture of small iron, as well as for blacksmiths' use. The kind of iron needed, in this case, may be considered the connecting link between the quality necessary for making heavy iron, and that for making wire.

e. Wire iron should be strong, hard, and tough. That which is fibrous, but not strong, is of no use; the wire made from it will be rotten, and without lustre. Where fibrous iron is employed for this purpose, the fibres must be very fine, and the color of the iron white. If the iron is bright, coarse fibres make rough, scaly wire; but if it is fibrous, and of a dull color, the wire will be both rough and rotten. Iron rendered cold-short by silex or phosphorus is not adapted for wire manufacture; but, when rendered cold-short by carbon, it will form, for this purpose, the most advantageous material available. Iron which is hot-short on account of sulphur is very apt to break in drawing. That which is hot-short in consequence of a deficiency of impurities is a still worse article. Very pure iron is so weak that wire cannot be made from it. The strongest kind of wire is made from an iron which contains just sufficient copper to make it decidedly hot-short. Wire iron must be very uniform in its aggregate form; that is, the billets from which wire is to be drawn must have a uniform texture throughout. It must not be a conglomeration of fibrous iron, cast iron, and steel. It requires dextrous workmen to make a good article even from excellent metal. The Catalan forge is not adapted for this purpose, even though the iron should be the product of the best of all materials; it does not work with sufficient regularity. White coke or anthracite metal will not make wire iron, even with the greatest attention, and in the best charcoal forge. Very nearly the same may be said of hot blast and white charcoal metal smelted from the poorer ores of the coal formation, and bog ores. White metal from the rich magnetic ores of New York, New Jersey, and Missouri, answers excellently,

if carefully worked in a charcoal forge. The best wire iron is made, in the puddling furnace, from cold-short gray charcoal pig, or from any gray pig iron, whether charcoal or anthracite, provided the metal is of such a quality that no difficulty results from boiling it. Neither the best nor the inferior qualities of white metal will make good wire iron in the puddling furnace. Iron of fine grain, or fine fibre, of uniform texture, great lustre, and of a somewhat bluish color, and soft as well as very tenacious, is that upon which our principal reliance must be placed. From this, it is evident that wire iron may be most profitably made in puddling works where boiling is well managed. In such establishments, the finest and strongest rough bars may be reserved for wire iron. A selection may be more safely made from billets than flat bars; and cold-short is to be preferred to fibrous iron.

f. Iron for the manufacture of railroad, coarse bar, boiler-plate, and common sheet iron, is to be of a different texture from wire iron, merchant bar, and thin sheet iron. That which is designed for these purposes is exposed to the heat of the reheating furnace in large piles, blooms, or slabs, to prevent the oxygen of the flame from abstracting the carbon from the interior of the pile so soon as would otherwise be the case. It should be white and fibrous in the rough bars; otherwise, it will be very cold-short by the time it is transformed into the proper shape. Another reason why such iron should be fibrous and white is that cold-short iron, reheated in heavy piles, is liable to great loss in the furnace. Before the interior of the pile can be heated to a welding heat, the exterior is melted and wasted. The iron most liable to loss in the reheating furnace is the very best and finest. To avoid this waste, and at the same time to secure a perfect heat, heavy piles are composed of different qualities of iron. The top and bottom bars are generally refined mill bars or a superior quality of rough bars. Mill bars will resist a higher and a more prolonged heat than rough or puddled bars, and are, therefore, commonly employed. A pile

thus formed—that is, composed inside of iron which can be welded by a lower, and outside of iron which requires a higher heat—will answer best with respect to quantity. Of quality we shall speak hereafter. For heavy work, the iron must resist a high heat, and often a heat of long duration. For these reasons, we require white, fibrous iron. Iron which, in consequence of the absence of carbon or other matter, is not cold-short, is advantageous. Such iron requires, and will bear, a higher heat for welding than that which is less white and less fibrous. At the same time, it will yield better, and not waste away so fast. Therefore, in selecting qualities of rough bars for the different purposes of the merchant mill, iron of fine grain or fine fibre must be chosen for the lightest kind of rod iron, such as wire and small rod; coarser, though not fibrous, iron, for hoops and all kinds of flat iron; fibrous iron of a dark color for square and round merchant bar; and white fibrous iron for heavy bar, boiler-plate, and railroad iron.

g. The piling of iron for the reheating furnace is, as far as quality and quantity are concerned, an object of the utmost importance, and too much attention cannot be paid to it. In a well-managed rolling mill, every rough bar is tested, and classified according to its texture. All the iron may be equally good, the grained equal to the fibrous; but the texture of the rough bars has an influence upon the quality and quantity of the article made from them. These bars must be straight, to admit of close packing, and they are to be sound and smooth on all sides, to offer a compact and close surface to the influence of the flame. Cold-short is more easily welded than fibrous iron; and dark iron will adhere together at a lower temperature than white iron. This, of course, is to be applied to iron made from the same metal, and in the same forge. Accordingly, the puddled iron, or rough bars, are to be classified into grained or cold-short, dull or dark fibrous, and bright or white fibrous iron. The second is the worst class; the first is designed for small, and the latter for heavy iron. These classes ought to be kept separate, and mixed at the reheating

furnace according to the kind of pile made, or the commercial iron which is to be manufactured from it.

It is easily understood that, on the piling of the rough bars, success in a great measure depends. If it should happen that cold-short or dark iron were put at the outside, or bottom, or top of a pile, it is very clear that the outside would be melted and wasted before the inside could be welded. The same happens if, accidentally, all the bad iron is on one side of the pile, and all the good on the other. This matter ought never to be left to accident, but it should be regulated with reference to the quality of the iron. Heavy piles of rough bars for reheating are to be composed, in the centre, of the weakest iron; at the bottom, of that next in quality; and on the top, of the best. Or, if there are but two classes, then the weaker at the bottom, and the stronger on the top. Where bar iron, weighing from 50 to 150 pounds, is to be made, it is most advantageous to mix the metal alternately, that is, to change with each single bar, so that not more than one bar of each class is joined by that of the next class. A uniform mixture will thus be made, and the best iron produced which can be made from the quality in question. If we reflect upon the difference which exists in iron of the same quality, but of different form of aggregation, with respect to welding at a high or a low heat; the cold-short iron, made from the same metal, will waste away, while the fibrous iron is not yet sufficiently hot for welding; if we further reflect upon the accidental running together of one or the other class of iron, in the same pile or the same heat, irregularly, which cannot be avoided where the rough bars are not tested and classified, we must not wonder when we see one pile yield ninety-five per cent., while the other makes but eighty; or when we see the splitting of blooms or the falling off of pieces in the roughing rollers. If each pile, as we have stated, is thus composed of a systematic range and quality of rough bars, the yield is uniform in the single piles, and of course better in the whole. There is then no splitting of piles, or waste in the rollers. This is always true, whether the manufactured iron be of

the worst or the best kind, the weakest or the strongest. All iron, if uniform, no matter what its quality may be, yields better and works better than it would under other circumstances. A pile of dull, weak, fibrous iron will be wasted away in a temperature scarcely strong enough to heat a good charcoal bloom sufficient for drawing, much less for welding. How imprudent would it be to put such different kinds of iron together in the same heat! We can very easily conceive the result of an attempt to weld a flat rough bar of weak puddled iron into a bloom of good white charcoal iron, without making the experiment. The weak iron will, of course, be wasted before a heat sufficient for welding is raised. It is unprofitable to weld weak iron to strong iron. It is a generally known fact that we can unite iron of the same texture, whether weak or strong, with the smallest possible loss. These remarks we deem sufficient to awaken more general attention to the classification of rough bars than is paid to it at present. Where iron is puddled from white or refined plate iron, the difference is not so striking as in establishments where gray pig is boiled. The difference is most apparent where boiling and puddling are carried on in the same mill, as at Pittsburg, and at almost all the Western puddling establishments.

h. An object of considerable importance is the manufacture of sheet iron; this, as well as bar iron, is generally made in the same establishment. So long as charcoal iron is used in the manufacture of sheet iron, which is commonly the case, it does not make much difference where the latter is made. But, if it is to be manufactured from puddled iron, it is of some consequence to use iron of a particular quality. A fine, fibrous, tenacious iron, of a bluish color, though not too white, is required. Hot-short iron is, of all kinds, the very worst, because it splits, and gets porous and scaly in the progress of the manipulation. Cold-short is not good for heavy, but answers well for very light sheet iron, such as stove pipe; it makes a smooth and polished surface. Here, as well as in the manufacture of bar iron, the iron is to be classified according to the purposes for which it is

designed. Classification is, in fact, of more importance in the one case than in the other. The price of sheet iron justifies the application of better pig metal, and more careful and expensive work in the forge, than would be prudent with bar iron. The price of the latter is, generally, so low, that a scrupulous adherence to quality is scarcely admissible. Badly worked iron, whether from the charcoal forge or the puddling furnace, is not adapted for the manufacture of sheet iron. For these, and many other reasons, sheet and bar iron ought not to be made in the same establishment, and from the same kind of iron. That which is most profitable for bar iron will make neither good nor cheap sheet iron; and that which makes the best and cheapest sheet iron is too expensive to be used for making bar iron. Blooms for sheet iron should be of the purest and best kind of iron, and of that which is most free from sulphur, silex, and phosphorus, and rendered cold-short by nothing else than carbon. For light sheet iron, cold-short iron is preferable, because it works easily, and takes a brilliant and durable polish. It does not oxidize to the same extent as a more pure and fibrous iron, and for this reason takes a more uniform color, and does not scale. On light sheet iron, we always look for a rich, bluish color and high polish. Well-polished, hard rollers and clean iron secure any degree of polish; but, to succeed well in this case, a particular kind of iron is required, which separates easily from the scales, or hammer-slag. The purest iron is that made cold-short by combination with a little carbon. White, fibrous iron is apt to form thick and heavy scales of hammer-slag, which adhere strongly to the iron, and are deeply impressed in its surface. These scales are removed with difficulty; acids are our only reliance, because many small particles of hammer-slag are so deeply squeezed into the iron, that nothing short of solution can remove them. After their removal, such sheet iron looks rugged and uneven. Good iron, of a steel-like grain, if properly treated in the heating oven, does not form these thick and uneven scales.

To make heavy sheet from cold-short iron is an unsafe policy, for, if we leave the quality of the former out of the question, its quantity is unfavorable. Cold-short, or weak iron, if rolled from heavy slabs or piles into boiler-plate, is very apt to split or open in the centre; this is a great loss, for, in most cases, the whole sheet is turned into scraps. Besides the loss caused in the rollers, we always find the central part of such plates very weak, scarcely better than cast iron, though the edges may be good. Heavy sheet iron and boiler-plate should be made from a coarse, fibrous, white iron, which will stand a high heat in welding. Boiled iron, and iron from hot blast worked in the charcoal forge, are unprofitable. Such iron will either spoil the sheet, or make it of such bad quality that it would be dangerous to put it in steam-boilers, and thus run the risk of destroying human life and property by explosion. Heavy sheet iron should be made from blooms which are manufactured, in the charcoal forge or the puddling furnace, from white, and the very best kind of plate iron; or, if not made from plate iron, the blooms must be rolled into flat bars, piled, reheated, and then rolled into flat mill bars, to be again reheated; this is repeated until the iron assumes a strong, fibrous texture and a bright color. If the latter cannot be produced, it is necessary to reject the iron altogether, at least for the manufacture of boiler-plate. This method of refining iron, which is frequently practised in England, is too expensive in this country; and, in addition to being expensive, it is ill adapted to make iron of proper quality, that is, strong in every direction. It will be strong in the longitudinal direction of the fibre and bars, but very weak in the transverse, that is, across the fibres. Coarse, weak, fibrous iron is to be considered in the same light with respect to the making of sheet iron, as to the making of wire. The sheet from such material will be porous, scaly, and weak, and will not answer the purposes for which it is designed.

In the erection of works for the manufacture of sheet iron, too much attention cannot be paid to the solidity

and strength of the machinery, and to a surplus of power. Success depends as much on an unfailing power and well-constructed machinery as on the well-trained intellect which manages the daily operations.

i. Nails are an important article of commerce, and an item in our factories which must be regarded with due attention. For these, good iron is unnecessary; they require neither strength nor the quality of welding, which are two requisites of iron the most difficult, at least the most expensive, to produce. Nail iron must be malleable, that is, in one direction, and as cheap as possible. Sheet iron, which is now most generally employed in the making of nail plates, is ill adapted to make a cheap, and, at the same time, a good nail. So long as good charcoal iron is used, the quality of sheet iron is secured; but, if an inferior quality of charcoal blooms, or puddled iron, is employed, the form of the sheet iron does not answer so well; the nails will be cold-short, though made from an article which, for the manufacture of bar iron, would be highly useful. In New England, nail plates from four to six inches wide, and from ten to thirty feet long, are made. These are preferable to sheet iron; that is, where the quality of iron is the same, a far better nail can be made from these plates than from broad plates or sheet iron. As previously stated, we are enabled to make fibrous and very malleable iron from almost any kind of pig iron, whatever its quality may be, provided there is no necessity of making the iron very cohesive, or of giving it the property of welding in the blacksmith's forge. Such iron is made in the puddling furnace by a very low heat, and it must be reheated at the lowest possible temperature; otherwise, it will lose its fibres and malleability, and become cold-short. It cannot be transformed into sheet iron at all; but it will make a hoop very malleable lengthwise, though not transversely to the fibres. It cannot resist a long-continued red heat, which is frequently applied to the nail machines, without altering its fibrous into a cold-short texture. Such iron, if well worked, is generally very soft; it may be

cut when cold, and then tempered so as to give color after the cutting of the nails. This is a proposition, however, not based upon practice, and requires confirmation. Iron of this kind can be made from pig iron, no matter how bad its quality may be. Puddling does not at all improve its purity; it only alters its texture from a granulated into a fibrous aggregation. Of all kinds of iron it is the cheapest, for it is worked fast, with but little loss, and little fuel; no skill is required to manufacture it. Industrious work and the lowest possible heat are the best means of success in puddling. Such iron is of but little use for other purposes, but we verily believe it will make a nail far superior to most of the nails at present in market. To make nails from white, coarse, fibrous iron, however strong it may be, is unprofitable, for the nails will split, and cut badly. Such iron is of too good a quality, and is better adapted for making coarse bar or heavy sheet iron. Whatever may be the kind of iron used for making nails, it is always better to draw it into long and small nail plates; these are to be cut into strips crosswise, so that the nail can be cut parallel with the length of the plate and fibres. The piles for making nail plates are to be put together with due regard to the production of the most perfect fibres. All cross piling is to be avoided; and if cold-short iron is to be worked at all, it must be mixed regularly in alternate courses with fibrous iron. Such piles may be very heavy; the greater the number of cuttings of rough bar, the better will be the result. The rolling of these piles is to be performed in such a manner as to make the welding joints parallel with the surface of the nail plate. In the reheating furnace, the lowest heat commensurate with the performance of the operations is the most profitable. Any heat relatively too high will transform most kinds of fibrous iron, particularly this, into cold-short iron, or iron of a crystalline texture. In the technical management of a rolling mill, we cannot pay too much attention to the classification of the puddled bars, and the composition of the piles, before they enter the reheating furnace.]

Siemens' Regenerative Gas Furnace.

This furnace is the joint production of the Siemens brothers, and operates upon the principle of the hydro-oxygen flame. The hydrogen is replaced by carburetted hydrogen of coke gas, and the oxygen by the atmospheric air. But added to this statement it must also be said that the gases, before they are combined, are heated in the following manner: The flame passing away from the puddling furnace is extremely hot. It has completed its work, and then, in the ordinary furnace, has passed off into the chimney and air as wasted heat. In this new furnace, this hitherto wasted heat passes through a chamber, imparting its heat in great measure to that chamber, and then by a valve the air gas which otherwise would come to the puddling furnace cold is suddenly passed through that heated chamber and comes into the furnace hot. So that the principle of the Siemens' Regenerative Gas Furnace is a double one, the principle of heating the iron in a puddling furnace by combining, in proper proportion, heated currents of atmospheric air and coke gas. As these furnaces are coming into use very extensively, we shall enter more into detail. The advantages claimed are, use of slack coal and inferior coal, even lignite and peat; unlimited command of heat; purity of flame; increased durability of furnace, owing to uniformity of heat; command of the flame, rendering it carbonizing, or oxydizing, by adding atmosphere, or carburetted hydrogen; complete absence of smoke from the chimney stack; cleanliness in the furnace room, as the gas is made outside the building.

They have been introduced in Pittsburg, Pa., at Anderson & Woods, also at two steel furnaces at Messrs. Singer, Minnick & Co., nearly completed; at Trenton, N. J.; Troy, N. Y.; Lenox, Worcester and Nashua, in New England, and in various other localities.

The late Professor Faraday, in his last public Lecture at the Royal Institution, on the 20th June, 1862, described these furnaces in the following terms:—

"The gaseous fuel is obtained by the mutual action of coal, air, and water, at a moderate red heat. A brick chamber, perhaps 6 feet by 12 feet, and about 10 feet high, has one of its end walls converted into a fire-grate, *i. e.*, about half-way down it is a solid plate, and for the rest of the distance consists of strong horizontal plate bars where air enters, the whole being at an inclination such as that which the side of a heap of coals would naturally take. Coals are poured, through openings above, upon this combination of wall and grate, and being fired at the under surface, they burn at the place where the air enters; but as the layer of coal is from 2 to 3 feet thick, various operations go on in those parts of the fuel which cannot burn for want of air. Thus the upper and cooler part of the coal produces a large body of hydro-carbons; the cinders or coke which are not volatilized, approach, in descending, towards the grate; that part which is nearest the grate burns with the entering air into carbonic acid, and the heat evolved ignites the mass above it; the carbonic acid, passing slowly through the ignited carbon, becomes converted into carbonic oxide, and mingles in the upper part of the chamber (or gas producer) with the hydro-carbons. The water, which is purposely introduced at the bottom of the arrangement, is first vaporized by the heat, and then decomposed by the ignited fuel, and re-arranged as hydrogen and carbonic oxide; and only the ashes of the coal are removed as solid matter from the chamber at the bottom of the fire-bars.

"These mixed gases form the gaseous fuel. The nitrogen, which entered with the air at the grate, is mingled with them, constituting about a third of the whole volume. The gas rises up a large vertical tube for 12 or 15 feet, after which it proceeds horizontally for any required distance, and then descends to the heat-regenerator, through which it passes before it enters the furnaces. A regenerator is a chamber packed with fire-bricks, separated so as to allow of the free passage of air or gas between them. There are four placed under a furnace. The gas ascends through one of these chambers, whilst air ascends through the neighboring chamber, and both are conducted through passage outlets at one end of the furnace, where mingling, they burn, producing the heat due to their chemical action. Passing onwards to the other end of the furnace, they (*i. e.*, the combined gases) find precisely similar outlets down which they pass; and traversing the two remaining regenerators from above downwards, heat them intensely, especially the upper part, and so travel on in their cooled state to the shaft or chimney. Now the passages between the four regenerators and the gas and air are supplied with valves and deflecting plates, which

are like four-way cocks in their action ; so that by the use of a lever those regenerators and air-ways, which were carrying off the expended fuel, can in a moment be used for conducting air and gas into the furnace ; and those which just before had served to carry air and gas into the furnace, now take the burnt fuel away to the stack. It is to be observed, that the intensely-heated flame which leaves the furnace for the stack always proceeds downwards through the regenerators, so that the upper part of them is most intensely ignited, keeping back, as it does, the intense heat ; and so effectual are they in this action, that the gases which enter the stack to be cast into the air are not usually above 300° Fahr. of heat. On the other hand, the re-entering gas and air always pass upwards through the regenerators, so that they attain a temperature equal to a white heat before they meet in the furnace, and there add to the carried heat, that due to their mutual chemical action. It is considered that when the furnace is in full order, the heat carried forward to be involved by the chemical action of combustion is about 4000°, whilst that carried back by the regenerator is about 3000°, making an intensity of power which, unless moderated on purpose, would fuse furnace and all exposed to its action.

"Thus the regenerators are alternately heated and cooled by the outgoing and entering gas and air, and the time for alteration is from half an hour to an hour, as observation may indicate. The motive power on the gas is of two kinds—a slight excess of pressure within is kept up from the gas-producer to the bottom of the regenerator to prevent air entering and mingling with the fuel before it is burnt ; but from the furnace, downward through the regenerators, the advance of the heated medium is governed mainly by the draught in the tall stack or chimney.

"Great facility is afforded in the management of these furnaces. If, whilst glass is in the course of manufacture, an intense heat is required, an abundant supply of gas and air is given ; when the glass is made, and the condition has to be reduced to working temperature ; the quantity of fuel and air is reduced. If the combustion in the furnace is required to be gradual from end to end, the inlets of air and gas are placed more or less apart the one from the other. The gas is lighter than the air ; and if a rapid evolution of heat is required, as in a short puddling furnace, the mouth of the gas inlet is placed below that of the air inlet ; if the reverse is required, as in the long tube-welding furnace, the contrary arrangement is used. Sometimes, as in the enameller's furnace, which is a long muffle, it is requisite that the heat be greater at the door end because the goods, being put in and taken out at the same end, those

which enter last, and are withdrawn first, remain, of course for a shorter time in the heat at that end; and though the fuel and air enter first at one end and then at the other alternately, still the necessary difference of temperature is preserved by the adjustment of the apertures at the ends.

"Not merely can the supply of gas and air to the furnace be governed by valves in the passages, but the very production of the gas fuel itself can be diminished, or even stopped, by cutting off the supply of air to the grate of the gas producer; and this is important, inasmuch as there is no gasometer to receive and preserve the aeriform fuel, for it proceeds at once to the furnaces.

"Some of the furnaces have their contents open to the fuel and combustion, as in the puddling and metal-melting arrangements; others are inclosed, as in the muffle furnaces and flint-glass furnaces.

"The economy in the fuel is estimated practically as one-half, even when the same kind of coal is used either directly for the furnace or for the gas producer; but, as in the latter case, the most worthless kind can be employed—such as slack, &c., which can be converted into a clean gaseous fuel at a distance from the place of the furnace, so, many advantages seem to present themselves in this part of the arrangement."

Professor Faraday concludes his lecture with the following conclusive figures:—

"Carbon burnt perfectly into carbonic acid in a gas-producer would evolve about 4000° of heat; but, if burnt into carbonic oxide, it would only evolve 1200° . The carbonic oxide, in its fuel form, carries on with it the 2800° in chemical force, which it evolves when burning in the real furnace with a sufficient supply of air. The remaining 1200° are employed in the gas-producer in distilling hydro-carbons, decomposing water, &c. The whole mixed gaseous fuel can evolve about 4000° in the furnace, to which the regenerator can return about 3000° more."

The first regenerative puddling furnace in England upon Mr. Siemens' plan is working at the Bolton (England) Iron and Steel Works; making three shifts of eight hours each, daily, and taking out upwards of 7500 lbs. of iron in eighteen heats with a very low consumption of coal. It is said the saving in waste is two cwt. per ton, and that the quality turned out is superior to that of

ordinary furnaces.* It seems that the water formerly used at the bottom of the gas-making coke, as mentioned in Dr. Percy's description, was not found to be economically conducive to additional heat, as, although its decomposition would be the occasion of more hydrogen, in practice, it absorbed more heat than it generated, and in many furnaces it is abandoned.

It is obvious that the Siemens furnace competes only with other reverberating or air furnaces for all purposes for which the latter are required. Whenever, therefore, it is necessary, or thought to be so, to melt pig iron in an air furnace, in order not to contaminate it with the impurities of the coal, the Siemens furnace will prove successful and economical; but the moment it is found out that the iron can be melted with good coke in the cupola, without being materially injured in its quality, the superior economy of the latter furnace must decide in its favor. In a cupola we may count upon melting ten tons of iron with one ton of coke, while in the best air furnaces one ton of coal will melt only about two tons of iron. Even supposing that the Siemens furnace could do more than that (which, with intermittent working, is doubtful) the economy would still be on the side of the cupola.†

Mr. Bauerman, in his treatise,‡ describes the Carinthian gas-puddling furnace, the principle of which is so nearly allied to that of the Siemens furnace, that it may be here noticed, and the use of air-dried wood and lignite is interesting, but much more so the use of peat, any ordinary grade of which, we think, might be equally efficient both in this and in the Siemens furnace.

The fuel is air-dried wood, which is converted into combustible gas in the generator, a rectangular chamber, lined with fire-brick, of a capacity of about 14 cubic feet, by a stream of air introduced at a pressure of half an inch of mercury, through a lower branch of the blast main, entering below the grate of the fire chamber. The combustion of the gases is effected by a

* Engineering, June 21, 1867.

† Engineering, April 5, 1867.

‡ p. 281, Eng. ed.

second blast, introduced immediately above the fire-bridge, through an inclined tuyere, which is of an oblong form, extending through the roof of the furnace and completely across the bridge, with an aperture of 7 inches in depth. By previously circulating through the hollow space in the cast-iron side plates of the bed, the air is heated to a temperature of 200° , producing a much more active combustion than is the case when the gases are burnt with cold air. A second bed is used for heating up the metal for the following charge by the waste flame during the period of balling, an arrangement that, as has already been stated, is found to save both time and fuel. The remaining details do not call for any particular remarks, being of the ordinary kind adopted elsewhere.

In Styria, where lignite is used for puddling, the consumption is from 22 to 24 cwt. per ton of blooms, a result that is highly favorable, not exceeding the average of furnaces where coal is burnt, allowance being made for the difference in calorific value of the two classes of fuel. This is in great part due to the high quality and small amount of carbon and silicon in the pig iron operated upon. The heat of 4 cwt. is worked off in an hour, having been brought to an orange-red heat before melting by exposure in a second hearth, during the balling of the preceding charge. The loss of weight on the metal is from 6 to 10 per cent. When peat is used, from 240 to 360 cubic feet are required in the production of a ton of blooms, or from 200 to 280 cubic feet of wood. From the published accounts of the working of furnaces using these fuels, there does not appear to be much difference whether they are burnt on a grate, or previously converted into gas, in the manner described above. The most economical work appears to be at Newberg, in Styria, where only 100 cubic feet of air-dried wood are consumed in the production of a ton of blooms. The metal, of a white or strongly mottled character, smelted with charcoal from spathic ore, is puddled in a double furnace, in charges of 8 cwt.; the heat lasts two hours, the loss of weight being from 5 to 6 per cent. At Lippitzbach in Tyrol, one ton of blooms is produced from 1.047 tons of pig iron, with a consumption of 1.011 tons of wood scorched or torrefied.

The Ellershausen Process.—This process of making malleable iron, which has attracted considerable attention for a year past, has been so well described in a communication to the New York Times, that we shall extract the important parts as follows :—

The process consists in the conversion of crude cast iron, as it runs from the smelting furnace, into wrought iron by the simple admixture of granulated iron ore. It is carried out at the works of the Messrs. Shoenberger & Co., at Pittsburg, in the following manner: On the casting floor of the smelting furnace a cast-iron turntable, about eighteen feet in diameter, is revolved on rollers by a small steam engine. Upon the outside edge of the table stands a row of cast-iron partitions, forming boxes say twenty inches wide and ten inches high, open at the top. Just above the circle of boxes stands a stationary wide-mouthed spout, terminating in the tap-hole of the furnace. When the furnace is tapped the liquid iron runs down this spout, and falls out of it in a thin stream into the boxes as they slowly revolve under it, depositing in each a film of iron say one-eighth of an inch thick. But before the fall of melted iron reaches the boxes it is intercepted, or rather crossed at right angles, by a thin fall of pulverized iron ore, which also runs out of a wide spout from a reservoir above. These two streams or falls are of about equal volume, say one-quarter of an inch deep and twenty inches wide. A workman, with a bar in the tap-hole, regulates the stream of iron, and the iron spout from which the liquid metal falls into the boxes is removable, other spouts, previously coated with loam and dried, being attached to a common revolving frame, so as to be ready for use when the loam covering of the first becomes crooked or removed. The thin layers of iron and ore soon chill and solidify, so that by taking away the outer partition of the boxes (which form the rim of the turntable) they may be removed in cakes the size of the boxes and weighing about two hundred pounds each. Four of these cakes or blooms are put into a reverberatory puddling or heating furnace and raised to a bright yellow heat. They will not melt at this, but become softened so as to be easily broken up with a bar. The four blooms are formed in the furnace by the rabble of the workman, as in ordinary puddling operations, into eight balls. The balls are brought out one after another, squeezed in the ordinary squeezers to expel the cinder and superfluous ore, and then rolled into wrought-iron bars, which are now ready for market, or for further reduction into smaller finished forms. The chemistry of the operation is as follows: The crude cast iron contains say five per cent. of carbon and two per cent. of silicon, and more or less sulphur, phosphorus, and other impurities. In the Bessemer process the oxygen of the air, blown into the liquid iron, combines with this carbon and these other impurities, and not only renovates them, but leaves the pure iron in a liquid state, from which it can be cast into homogeneous masses of any size. In the puddling process the oxygen of

the air and of the ore, or other fettling, put into the furnace with the iron, combines with and eliminates the impurities which are afterwards squeezed out of the pasty mass by the squeezers and rolls. This process is long and comparatively expensive, because the mixture of oxygen or oxygen-bearing substances is not made intimate with the iron except by long stirring, which is not only skilful but exhausting work. In the Ellershausen process the oxygen of the ore, or oxide of iron (magnetic oxide is preferred), combines with the carbon and impurities, eliminating them as in the puddling process; and the iron of the ore increases the product. The chemical combination of the ore and the liquid crude iron appears to take place partly at the time of their contact, when falling and lying upon the turntable, and partly when the reheating occurs in the furnace. It seems impossible that a reaction which is so violent in the Bessemer process, and so prolonged in puddling, should take place so quickly and quietly in the new process; but the fact that the cakes of iron and ore do not melt by subsequent heating, as cast iron would, proves that its nature is changed by the first contact of the ore. The removal of sulphur and of phosphorus also seems more thorough than in the other processes. Analyses at different stages of the operation will throw more light on this question. The remarkable feature of the Ellershausen process is that absolutely no skill is required to carry it out. The proportion of ore mixed is intended to be about thirty per cent., but if too much is added it is readily squeezed out with the slag, and seems to do no harm. The subsequent heating occupies about half an hour. "Puddle bar," the product obtained from the first rolling of the product of the puddling furnace, is never marketable or finished iron. It is usually very ragged and unsound, and requires subsequent piling, reheating, and re-rolling, to expel the impurities, and to give it soundness and solidity. The new process appears to produce merchantable iron at the first rolling, at Pittsburg, from a very inferior pig iron, made of one-half sulphurous Canada ores and one-quarter Lake Superior and one-quarter Iron Mountain ores. The thoroughness and rapidity of the purification by this process evidently depend on the intimacy of the mixture of iron and ore. This intimate mixture is also the essence of the Bessemer process. In fact, to Mr. Bessemer's apprehension of this idea of intimate mechanical mixture the greatest modern improvements in iron manufacture are due.

The Ellershausen process is said to decrease the cost of wrought iron from \$10 to \$20, or \$20 per ton according to the materials used and the form of product required; its success is said to be amply proved by regular working at Pittsburg and

many experiments elsewhere; and if anything like this economy can be realized, its value to the public will only be exceeded by that of the Bessemer process. The latter process, however, produces steel which is absolutely homogeneous, and of regulated hardness according to the wear and service required, and hence indispensable for rails, tyres, and various machinery purposes. Any iron product that is not cast from a liquid state is subject to all the structural defects of wrought iron.

1. The philosophy of this process is found in the fact, that any substance having an affinity for carbon will take that carbon away from the cast iron which is a compound of iron with more than two per cent. carbon. Anything which will sufficiently abstract the carbon, will reduce the cast iron to malleable iron. Now the oxygen of the ore combining, under great heat, with the carbon of the cast iron abstracts the carbon from the cast iron, forms the CO^2 , which, as previously shown, disappears in the atmosphere and leaves the iron malleable, or without carbon.

2. The novelty of using ore for this purpose consists in the machinery used and in the application of the ore to the melted cast iron. In these respects the process is novel. Any one may see, by consulting the Franklin Journal so far back as July, 1826, the following quotation from the London Journal:—

“On page 185 of above Journal it is said of making malleable cast iron, that castings thus made were put in pots along with and surrounded by a soft red ore, and a regular heat kept up for seven days or two weeks, depending on the thickness or weight of the casting. Cast horse shoes, after being worn out, are converted into penknives and other cutlery; they are made from pig iron containing the smallest amount of carbon.”

The principle involved, namely, of using rich ores to decarbonize cast iron into malleable iron, is not discovered, but applied in a much more efficient and interesting manner as the molten pig, instead of the simply red hot pig, expedites the operation.

3. Unless the cast iron is of the purest quality, and the ore used is a fine, pure magnetic, or red hematite,

entirely free from sulphur, phosphorus, and silex, we cannot see how the hurtful ingredients can be eliminated. If the ore were entirely free from sulphur and phosphorus, we think that the tendencies would be to cold-short iron, because of the thorough and minute intermixture in the iron of the silex from the ore.

In March, 1869, we received the following communication from the Messrs. Shoenberger & Co., of Pittsburgh, Pa.

“ We have manufactured over three thousand tons of the pig bloom into horse-shoes, sheet iron, and nails, and we are much better pleased with it to-day than we were three months ago. In manufacturing horse-shoes, we had formerly to make them entirely of scrap iron; now we are making fully as good a shoe from billets rolled direct from the puddled ball as it comes from the boiling furnace, and from a common article of coke pig iron. Our nails and sheet iron are much improved, and we have rolled No. 36 sheet iron free from holes and breaks, direct from the muck bar made by the Ellershausen process. The cost of turntable, etc., to make the pig bloom is about twelve hundred dollars without the power. It is not necessary to change any of the other arrangements of the mill, but if you increase the size of the puddling furnaces you will largely increase the yield and the quantity.

“ We are now working our furnace a foot and a half larger than the old furnaces, and it is producing from 6000 to 6300 pounds per single turn of six heats; and the loss on the pig bloom (which is thirty per cent. ore and seventy per cent. pig iron) in only fifteen per cent. in putting it into muck bar. We have tried many different kinds of ore, and they all work well, but the purer the ore the less will be the loss in the after-treatment. If there is a very large amount of sulphur in the ore it will sometimes show in a slightly red-short tendency, but any reasonable amount will be driven off. The first great point is to have a thorough mixture of the iron and ore (about one-third ore); it will then not boil in the furnace, will not melt down, and will greatly improve the quality of the iron. The pig bloom should be in medium-size pieces (not scrap), so that it will get heated through thoroughly; if they are too large, the outside will be heated up and come to nature, and the centre will be raw.

(See *Frontispiece*.) “ The turntable, or circular trough, turns from four to six revolutions per minute. The right-hand trough leads the molten iron from the blast furnace to the receiver,

which is as wide as the turntable, and spreads the metal so as to flow the width of the table. The left-hand spout delivers the ore (any ore containing plenty of oxygen, crushed into small grains) at the same place and the full width of the table; it mixes then, and one layer after another is built up as the table turns round, each revolution making a layer, and all matted together. Cast-iron plates are placed across the table to cut up the mixture into pieces fit for handling."

Finding that the process required still more accurate and scientific examination, Jas. P. Speer, Esq., of Pittsburgh, engaged the services of Dr. Wurth, who, after considerable care, has furnished us with the following extended report:—

The pig bloom formed by the Ellershausen process consists of a conglomerate of partially decarbonized pig iron and granulated iron ore (100 pig metal, thirty ore). This conglomerate properly made—and a very short experience of the workmen will enable them to obtain alway a good mixture—when worked in the puddling furnace almost retains its original shape. The great difficulty of bringing the iron and the oxides in contact in order to decarbonize the melted pig iron, as experienced in the boiling process, is by the Ellershausen method overcome.

The immense surface offered to the action of the intermixed ore, causes the pig iron to be decarbonized without becoming liquid first, as it does in the puddling furnace. The carbonic oxide whose escape through the liquid mass of iron and slag causes the boiling in the puddling process, passes off through the porous conglomerate without being noticed. The wrought iron manufactured by the Ellershausen process, is of better quality than that made by the puddling process. I have the most positive assurance of different iron masters, who have experimented with the process and have often seen the practical results myself. (Iron extremely red-short when puddled becomes neutral by the Ellershausen process; these experiments were tried with the same results with different kinds of iron.) The analyses show that the sulphur is eliminated to a far greater extent than by the puddling process, also the silicon; while the phosphorus is removed at least as well as can be done by the most careful puddling. (See analyses.)

The iron produced from a pig containing considerable quantity of copper, treated with Cornwall ore (Lancaster Co., Pa.), of 0.15 per cent. of copper, was very red-short, but it is the same when puddled.

At the works of Messrs. Shoenberger & Co., nearly 4000 tons

of wrought iron have been manufactured by the Ellershausen process, little over twenty-eight per cent. of iron ore (magnetic and iron mountain, Mo.), have been used in forming the conglomerate, and the increase over the weight of pig metal in muck bar was nearly five per cent. Taking this figure and putting the loss in puddling only at five per cent., there is a gain of ten per cent. over the old method. While as a general rule, in the puddling process there are at least 100 lbs. of scrap iron needed per ton of muck bar to fix the bed of the furnace, also a considerable varying quantity of ore and cinder, nothing is wanted when working the Ellershausen pig bloom with the exception of about 40 lbs. of ore per ton of iron. The time required to work 800 lbs. of conglomerate, which yields about 600 lbs. muck bar, is *not over* one hour and a quarter in a well constructed ordinary single puddling furnace, and as there is no time required to "fix" the furnace after every five or six charges, seven charges can easily be made per shift, the production of the furnace being 4200 lbs. against 2400 lbs. in the puddling process. The amount of coal burned per ton of iron cannot be much more than one-half of that used in puddling; in fact numerous experiments tried by Mr. Wm. M. Lyon, of this city, have proved it to be so. The amount of tools in use per ton of iron manufactured is of course much smaller, and not much over one-half of the number of furnaces are required, and have to be kept under repairs. As the puddler with less labor can almost make twice the weight of wrought iron which he could formerly by boiling, he cannot reasonably expect to be paid the same wages as before (per ton). While pig metal is used for the manufacture of wrought iron, the production of it directly from the ore being so far of little importance, you can rest assured that the Ellershausen process will take the place of puddling universally as surely as puddling has succeeded the charcoal forges.

The ore used for mixing at the works of Messrs. Shoenberger & Co. are magnetic of 65 per cent. iron with no sulphur and only a trace of phosphorus, and iron mountain red hematite of the same percentage of iron. The ore used by Messrs. Lyon, Shorb & Co. is a brown hematite, containing 0.21 phosphoric acid, 60 per cent. peroxide of iron, 13 per cent. water, balance almost entirely silica and alumina.

Analyses	a	b	c
Carbon chem. comb. .	2.87	0.43	0.39
Graphite . . .	1.34		
Silicon . . .	1.02	0.20	0.09
Sulphur . . .	0.14	0.011	0.006
Phosphorus . .	0.58	0.12	0.14
Iron . . .	92.46	—	—

Copper, cobalt, calcium, aluminum, and slag not determined.

(a). Pig metal from Shoenberger & Co., coke metal smelted from Lake Superior, Sterling & Marmora ores (only small amount of the two latter ones).

(b). Puddled iron from the same.

(c). Wrought iron of the same metal by the Ellershausen process.

A pig metal smelted from very sulphury stock at the works of Messrs. Shoenberger & Co. contained 0.42 sulphur; the wrought iron from the same, puddled, contained 0.027, when worked by the Ellershausen process only 0.012.

	<i>d</i>	<i>e</i>	<i>f</i>	<i>g</i>	<i>h</i>	<i>i</i>
Iron	93.01	94.45	—	—	—	—
Manganese	0.21	trace cob.	—	—	—	—
Silicon	0.93	0.41	0.17	0.16	0.07	0.05
Phosphorus	0.57	0.22	0.25	0.22	0.16	0.15
Sulphur	0.03	0.009	trace	trace	trace	trace
Carbon comb.	1.05	1.34	0.34	0.29	0.31	0.24
Graphite	3.86	3.18				
Slag and trace CuAlCoCa	6.34	6.40	—	—	—	—

(d). Pig metal from Sligo furnace (Messrs. Lyon, Shorb & Co.).

(e). " P enna. " " "

(f). Wrought iron from *d* puddled

(g). " " " Ellershausen process

(h). " " " " " "

(i). " " (e) " " "

	<i>k</i>	<i>l</i>
Silicic acid	14.02	8.95
Peroxide of iron	17.71	16.01
Protoxide of iron	60.31	68.88
Lime	2.08	1.74
Magnesia	0.84	0.85
Alumina	1.44	1.31
Phosphoric acid	2.54	1.74
Sulphuret of iron	0.88	0.72

(k) Puddled slag from *a*.

(l) Slag produced by the Ellershausen process.

The iron *a* was puddled with cinder from the puddling furnaces, while when worked by the Ellershausen process it furnished its own cinder, and it is for that reason that *k* contains a larger amount of phosphoric acid and sulphur than *l*.

This process is being introduced on a large scale at Burden's Iron Works, Troy, N. Y., in direct connection with the blast furnace. The turntable is twenty-six feet diameter and the mechanical arrangements are excellent. Prof. Maynard of the Rensselaer Polytechnic Institute, of that city, is engaged in making thorough

analyses of the ores and the finished products. Experiments have already been made with the Champlain magnetites, Vermont brown hematites, with mixtures of magnetites and black oxide of manganese, black oxide alone, and with the magnetic iron sands from the St. Lawrence sent by Dr. Sherry Hunt. Prof. Maynard writes us, that when the magnetite was used, the evolution of CO was quite plentiful, although by no means sufficient, as he supposed, for the complete elimination of the carbon, but in the balling the principal chemical action will probably take place. When the hematite was used there was no evolution of gas, the pig blooms from this treatment showed that the mixture is not by any means so complete as with the magnetic oxide ($\text{Fe}^3 \text{O}^4$). Experiments have been tried under the direction of Mr. A. L. Holley, who has large experience in the American Bessemer process and is thoroughly competent to judge of the value of the iron; and with the established skill of Prof. Maynard, who has the direction of the analyses, results of very important scientific and economic value may be expected.

This process has been introduced into Sharon, Pa., at the Westerman Mill, where the success is claimed to be decided; but in no place is the process so thoroughly and extensively attempted as at the works in Troy, N. Y.

Johnson's Furnace.—We shall only describe this furnace briefly, and yet sufficiently, to represent all the claims of success which, thus far, may justly be made for this furnace. It was only in Jan. 22, 1868, that Mr. Johnson received letters patent for this invention, which claims entirely to dispense with the costly blast furnace hitherto employed. The construction of the furnace is simply that of an ordinary blast furnace wherein are placed, vertically, a number, say twelve or more, refractory crucibles opening outside at the top of the furnace. These crucibles are perforated in the bottom, and into them are put the charges of ore and flux, with or without charcoal. The heat from the hearth, or Siemens gas generator, passing among these crucibles, melts the ore and flux, which flowing down run together out upon

the hearth which is inclined downward from the right and from the left to the middle of the furnace, where the iron settles covered with flux. At this lowest part, or angle, the tapping-hole is put.

Much is claimed for this furnace, but we presume that the advantages, as well as the disadvantages, may be readily seen by any one acquainted with the practical workings of the blast furnace. The main *advantage* would be found in the shielding of the iron, when dropping down through the flux, from the effects of sulphur and other impurities in the coal or fuel. This *would* be an advantage, and apparently the only one of much practical importance. The *disadvantages* would be the incessant destruction of the crucibles, and the small amount of iron made by this furnace when compared with the ordinary high furnaces. The purity of the iron made with the use of cheaper and more impure fuels is the most important element in the advantage for the decreased expense, due to the fact that smaller blast engines are called for in this than in the ordinary furnaces, would not be so important an item as to call for much attention. This furnace, however, needs considerable modification, as does the process of making malleable iron and steel, which is associated, in theory, with its operations in the general; we think, therefore, that it needs no further notice at this time.*

* The Practical Mechanic's Journal, June 1, 1869.

PART IV.

STEEL.

INTRODUCTION.

ALTHOUGH there has been no difficulty experienced for ages past, in making steel as such, there exist many mysteries connected with the manufacture which have never yet been satisfactorily explained. The generally accepted method of producing steel, or rather of transforming malleable iron into steel, is by the addition of carbon, or the combining of carbon and malleable iron in certain proportions, which we have indicated upon a previous page. But why carbon should produce this result is a mystery—why carbon, thus introduced, should cause iron to retain its magnetism is a mystery—why it should admit of tempering is a mystery, and yet these are the well-known distinctions of steel from iron, malleable or cast. Other ingredients than carbon will also influence, favorably, the formation of steel, or a metal answering all the conditions of carbon steel either with carbon or without any portion of carbon, as we shall see. Small proportions of aluminum, and especially of chromium, seem, with other alloys, to produce, without any portion of carbon, steel of superior quality, answering all the conditions (of a commercial value) of steel from carbon. Small portions of sulphur, phosphorus, silicon, seem in some cases to injure and in others only to modify without injuring the qualities of steel. Small portions of nitrogen seem to be essential in some cases, and yet, such is the uncertainty in other cases, that some of our best analysts are at variance either as respects its existence or its quantity.

Carbon Steel.

Steel by Direct Process:—from the Ore.—It is plain if malleable iron (combined with proportions of carbon ranging from 0.5 to 2.00 per cent.) becomes steel, that it matters not whether cast iron be decarbonized to these proportions, or malleable iron be carbonized to the same proportions—steel will result.

The earliest methods of making steel were, accidentally, the latter. When the rich ores were deoxidized by heating with charcoal, they became malleable iron—a little more heating with charcoal, carbonized them into steel. This was an early method of making steel, and perhaps adopted in the earliest ages, long before cast iron was known. Such is the method adopted in the Hindoo furnaces, in Burmah, at the present day, and in the Catalan forges of Italy and Spain. With skill a nearly uniform metal is the result; without it, a mingled mass of iron and steel, the latter more or less carbonized and therefore more or less steely.

In 1791 the patent granted to Samuel Lucas for making steel from rich ores in crucibles with carbonizing material, was nothing more or less than making steel upon the same principle. So, also in the case of David Mushet's patent in 1800, and still later 1836, in the case of John Isaac Hawkins. In 1854 the converting furnace, in principle similar to that now in use, was adopted for interstratifying iron bars with ore and carboniferous material, wherein, the ore seemed to be of no direct use in transforming the bar iron into steel, that result being due to the carboniferous material. In 1856, Wm. Edward Newton obtained a patent involving the very same principle worked out previously, in which the ore was deoxidized and then carbonized by being heated to whiteness with charcoal. And Dr. Percy says, the same experiments were tried by Mr. E. Riley, at the Dowlais Works a little later.

The process called Chenot's process is nothing more than another method of performing the same work of carbonizing the porous malleable iron obtained by

deoxidizing rich ores. This deoxidization leaves the ore porous and gives rise to the name of "metallic sponge" as applied to such ore. Such a state of porosity is easily understood when we remember that a pure sesquioxide of iron—(brown, red hematite)—contains of oxygen twenty-four parts in every eighty of the oxide. This metallic sponge was saturated with hydro-carburetted liquids, as resins, oils, &c., and compressed to two-thirds its size into cylindrical moulds, and melted in crucibles. The steel resulting has not been considered equal to first class English steel. After the above mentioned instances it may not be surprising that the same class of efforts are being continued, or that we have manufactories in various places, where the same principle is applied to rich ores from Lake Champlain and elsewhere, but the resulting steels, which we have examined, seem to exhibit more or less lack of homogeneousness.

Earnest efforts have been made at Clifton, on the Rome, Watertown, and Ogdensburg R.R., N.Y. The process employed is the patent of Dr. George Hand Smith, of Rochester, and is as follows: The ore being crushed to about one-eighth inch size, is mixed with about half its bulk of fine charcoal, and charged two tons at a time into a reverberatory furnace with a hollow bridge through which petroleum is passed. The carburetted hydrogen aids directly in reducing the ore. In about five hours the ore is deoxidized and carbonized into steel. The process in this instance does not seem to have been very successful. Another plan adopted at Ringgold, Schuylkill County, Pa., is by drawing the ore down from shelf to shelf to meet an ascending column of ignited charcoal particles and thus deoxidizing the ore. To these we might add other places, as in Mott Haven, N.Y. City, Massachusetts and in the West, none of them, however, differing in principle nor in economical results. These works, however, have not been in operation for a time sufficiently long to test what may yet be done. It scarcely need be added that ardent hopes are had that these attempts will succeed, and some good results are

exhibited. All the above processes may be classed under the head of carbon steel by the *direct process*.

Carbon Steel by Indirect Process:—from bar or malleable Iron; Steel of Cementation, bar or blistered Steel.—It is said that the iron imported from Madras, Sweden, and Russia into Great Britain, is of such a quality that it is capable of being converted into steel of quality superior to any manufactured from British iron, excepting the charcoal iron of the Ulverstone.

Swedish iron is the first in rank and commanded the highest price, formerly 36*l.* 10*s.* per ton, against excellent English coke-iron at 7*l.* 6*s.* per ton. (Ure.) It is supposed that this superior quality of the Swedish iron is due to the peculiar nature of the ore from which it is smelted. This is stated to show that the operation known as *cementation* is successful in proportion to the purity of the iron used.

In the following diagram is represented a ground plan, Fig. 226, and cross section, Fig. 227, of the Sheffield furnace for making bar or blistered steel, which is about the same in form with that which has been used for more than a half century, and is now used in our best furnaces at Pittsburg and elsewhere. It is called the furnace of *cementation*.

The hearth of this quadrangular furnace is divided by a grate into two parts, upon each side of which there is a chest *a*, called a *trough*, made of fire-clay or fire tiles. The breadth of the grate varies according to the quality of the fuel. *b, b*, are air-holes; *c, c*, flues leading to the chimney, *d, d*. To aid the draught of the smoke and the flame, an opening *e*, is made in the middle of the flat arch of the furnace. In one of the shorter sides (ends), there are orifices *f, f*, through which the long bars of iron may be put in and taken out; *g*, is the door by which the steel-maker enters, in filling or emptying the troughs; *h*, is a proof-hole, at which small trial samples of the steel in the act of its conversion may be drawn out. The furnace is built under a conical hood or chimney, from thirty to fifty feet high, for aiding the draught and carrying off the smoke. The two chests are

Fig. 226.

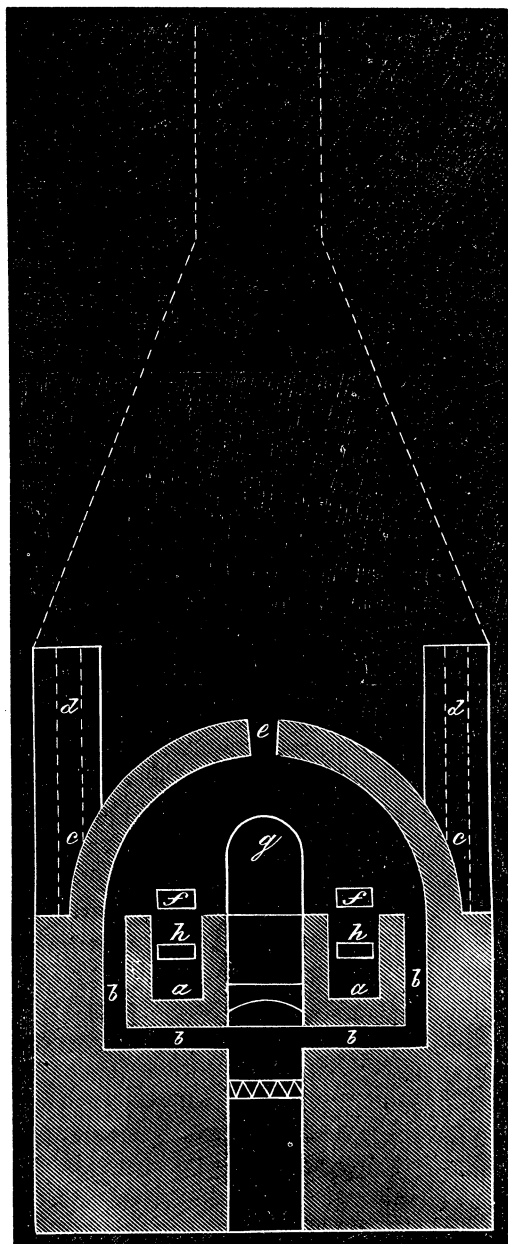
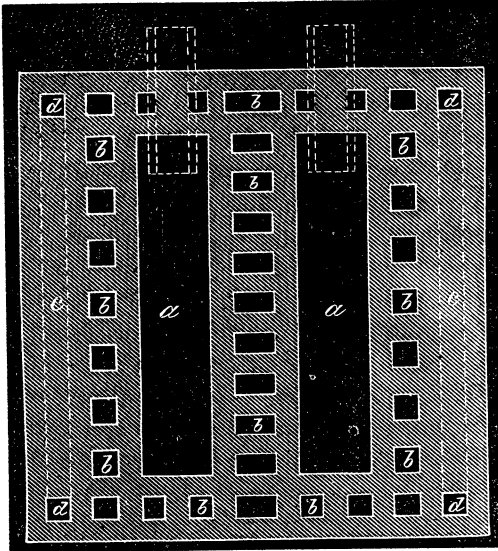


Fig. 227.



built of fire-stone grit, they are eight, ten, or even fifteen feet long, and from twenty-six to thirty-six inches in width and depth; the lower and smaller they are, the more uniform will the quantity of steel be.

A great breadth and height of trough are incompatible with equability of the cementing temperature. The sides are a few inches thick. The width between them is at least a foot; they should never rest directly upon the sole of the furnace, but must have their bottom freely played upon by the flame, as well as the sides and top. The degree of heat is regulated by openings in the arch, or upon the long sides of the furnace, which lead to the chimney; as also by the greater or less quantity of air admitted below the grate, as in glass-house furnaces.

The so called "*Cement*," used in place of pure hard charcoal, now prepared by steel makers, was a mixture of ground charcoal, common salt, and one-tenth of ashes. The salt it was thought united with the silica in the charcoal, and formed glass or slag, and thus prevented the silica from uniting with the steel, which would

render it hard; the use of the ash is unknown, but we may say that the potassa in the ash will also unite with the silica and form slag. We have said that the use of the ash is unknown, for its presence is not thought necessary to the manufacture of good steel.

Upon the bottom of the trough about two-inches of this cement is placed, and the bars are laid in it one-half to three-fourths of an inch apart, and one inch from the side, then half inch cement on these bars, and bars on the charcoal or cement again, and so on alternating cement and bars till the trough is filled within six inches of the top, which is filled with damp sand or old cement and fire-tiles. Some lute the top with clay. The object is to prevent all access to air. In the time of Reaumur, 1722, many recipes for cement were given and important secrets made of cements, hence the name "cementation."

As to the fire, this must be carefully urged from two to four days till it acquires the temperature of 100° Wedgewood; and this temperature must be maintained from four to ten days according to the size of the furnace and the harness of steel desired. At Pittsburg the time is generally eight or nine days. In the front or remote end of the furnace, Fig. 227, a door is left in the outer building, corresponding to a similar one in the end of the interior vault, through which the workman enters for charging the furnace with charcoal and iron bars, as also for taking out the steel after the conversion. In the end of the chests, called also converters, small openings are also made through which the ends of a few bars are left projecting, to be pulled out and examined at different times. The *tap* holes, as they are called, should be placed near the centre of the end stones of the chests, that the bars may indicate the average state of the process. The joinings of the fire-stones are secured with a finely ground Stourbridge clay, or by any material preventing the entrance of air. The interval between the two chests being covered with an iron platform, the workman stands on it, and sifts a layer of charcoal on the bottom of the chest evenly, about half an inch thick. He then lays a row of bars, cut to the proper

length, over the charcoal, about an inch from each other; he next sifts on a second stratum of charcoal dust, which, as it must serve for the bars above as well as below, is made an inch thick; thus, he continues to stratify, till the chest is filled within two inches of the top; and he covers this with any convenient fire loam. The bars should be so placed that those of the second series cover the interstices between the bars of the first and the third, those of the second, and so on in succession. The trial rods being longer than the others, their projecting ends are incrustated with fire-clay or imbedded in sand. The iron platform being removed, and all the openings into the vault closed, the fire is lighted, and very gradually increased, to avoid every risk of cracking the grit stone by too sudden a change of temperature; and the ignition being finally raised to about 100° Wedgewood, but not higher, for fear of melting the metal, must be maintained at a uniform pitch, till the iron has absorbed the desired quantity of carbon, and has been converted as highly, that is, the steel made is hard as the manufacturer intends for his peculiar object. The charcoal preferred at Sheffield is good white ash coal, and fresh coal is always used with the spent coal of the last charge. (Ure.)

From six to eight days is considered a sufficient period for the production of steel of moderate hardness, and fit for tilting into shear steel. If the steel is to be soft—for saws, springs, &c., the time is less than six days—if harder, for chisels for cutting iron, will need longer exposure to the ignited charcoal. In some cases when exceedingly hard steel is desired the bars are exposed to two or three successive processes of cementation. The higher the heat of the furnace, the quicker is the process of conversion. The furnace being suffered to cool, the workman enters it again, and hands out the steel bars, which are covered with blisters, from the formation and bursting of vesicles while the steel was soft, on the surface filled with gaseous carbon, some say carburetted hydrogen, Dr. Percy thinks CO from reduction of proto-silicate of iron, or from escape of sulphur

in the iron in shape of bisulphide of carbon. It is therefore called *blistered steel*. This steel is very irregular in its interior texture, has a white color, like frosted silver, and displays crystalline angles and facettes, which are larger the further the cementation has been urged, or the greater the dose of carbon. The central particles are always smaller than those near the surface of the bar.

When the iron is only to be case-hardened, the material used is composed of about ninety per cent. of charcoal, the remainder consisting of the carbonates of lime and potash. The articles are packed in this material in the usual manner, any parts which it is desired to prevent from becoming case-hardened being coated with clay. The time the articles are allowed to remain in the furnace varies from nine hours to forty-eight hours, according to their size and the depth to which it is desired the steeling shall penetrate.*

In a furnace of this size twelve tons of bar iron may be converted at a charge. In those prepared at Sheffield, seventeen feet by four feet, sixteen to eighteen tons are converted.

It is said that smaller furnaces will consume more fuel proportionally than larger ones. Such steel often contains fissures and cavities occasioned by the absorption and action of carbonaceous matter; if, therefore, these bars are desired for tools they must be made uniform and compact by means of a tilt hammer.

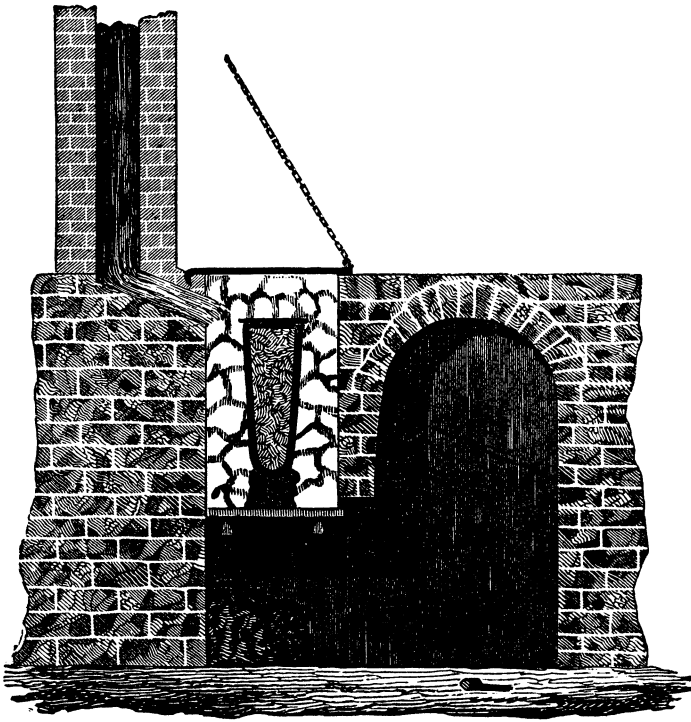
Shear Steel, so named because it is used for the manufacture of shears. It is made by taking five bars of blistered steel, four of which are about eighteen inches long and the fifth double this length to serve as a handle; these bars are bound into a fagot by means of a thin steel rod. This fagot is now placed in a forge hearth, and subjected to a good welding-heat, sprinkled over with sand so as to form a thin film of iron slag over it,

* See drawing of Dodd's case-hardening furnace, *Engineering*, Feb. 15, 1867, not however materially differing from that we have drawn above.

which serves for a protection. The bars are then notched and firmly united under the tilt hammer. It is then heated again and drawn out in rods of the size required.

Cast Steel.—This is made from blistered steel, broken into small pieces and melted in the best fire-clay, plumbago, or blacklead crucibles. Not any of the various methods of hammering and of compressing will produce perfect homogeneity of metal so well as re-fusion and casting. Hence, the following form of furnace is resorted to as adapted to the end had in view of obtaining sufficient heat for melting converted bar steel. This form is

Fig. 228.



Cast steel air furnace.

that, without any material alteration, adopted at the Pittsburgh, Pa., steel works, and at other places. The chimney stacks are usually about forty-five feet high,

and the draught is taken from outside the building through a subterranean gallery immediately under the floor. The drawing will sufficiently explain itself.

The furnace is a square prismatic cavity lined with fire-bricks, in some cases only twelve inches each side, and twenty-four inches deep, with a flue immediately under the cover three and a half inches by six, for conducting the smoke into an *adjoining* chimney. The ash pits end in a subterraneous passage which serves two purposes, an ingress for the cold air and an egress for the ashes. The crucible is placed on a piece of baked fire-clay or bottom of old crucible, and well covered with a lid. The fuel used is coke; the crucible is taken out by means of tongs, and the steel poured into cast-iron rectangular or octagonal moulds, previously heated and smoked. This steel is harder than shear, and cannot be subjected to a heat greater than cherry red without becoming brittle and useless; it is also less easily welded. It is said that if iron is well polished it can be elegantly plated by, or welded into, this steel. The process is simple, viz., by pouring over the polished iron the molten steel from the crucible. Thus by such combination, we have a metal which has the toughness of iron and the hardness of steel, and is well adapted to the purpose for which it is used, *i. e.*, for the manufacture of chisels. When the metal is unequally carbonized, that is, when the metal nearer the surface contains more carbon than the interior, it can readily be equalized by means of manganese (MnO_2). Heating the steel, thus unequally carbonized, in connection with manganese, the manganese parts with its oxygen which unites with the carbon of the steel and forms carbonic oxide (CO), or carbonic acid (CO_2) which escapes, and the steel becomes homogeneous and softer.

Indian Steel, or Wootz.—The ores are generally magnetic oxide, siliceous about forty-two per cent., and magnetic oxide fifty-eight per cent. The ore is pounded and separated from the stony matrix, preliminary to smelting, and the bar iron made from these ores is cemented. This steel is said to be the finest steel known, and is

used for the manufacture of the celebrated Damascus sword-blades of the East. English manufacturers, with all their experience and advantages, are unable to produce steel of an equal quality to this Indian wootz. Prof. Faraday attributed its peculiar excellence to the presence in its composition of a small quantity of aluminum. In corroboration of the supposition that the wootz steel contains aluminum, it is a fact that in the manufacture of steel good clay is mixed with an equal quantity of charcoal made from paddy husks, and having been well moistened with water, is thoroughly mixed by being trodden under the feet of oxen, it is then picked clean and made into cupels (crucibles), which are dried one day in the shade and next day in the sun. A fireplace is then built up composed of clay and stones, and furnished with two bellows. Each of the cupels is now loaded with a small piece of iron, from ten to fourteen ounces in weight, together with five small pieces of the Tangaree wood. Three rows of the loaded cupels are placed one above the other so as to occupy the whole area of the furnace, the room of one cupel being left empty opposite the nozzle of the furnace. They are then covered with two bushels of charcoal and burned for six hours, a third bushel of charcoal having been added as the former two are consumed.* The furnace in which the ore is smelted is a small and simple affair, in form is pear-shaped, and only four to five feet high, and about two feet wide at the bottom, and one foot at the top, made entirely of clay. A few men, it is said, can make one in several hours. The opening in front, which is about a foot in height, is built up with clay at the commencement, and broken down at the eve, of each smelting operation. The bellows are made of a goat's skin. This skin is taken from the animal without opening the part covering the belly. The apertures at the legs are tied up, and a nozzle of bamboo is fastened in the opening formed in the neck. The orifice of the tail through which the air is admitted is closed while the stroke is made, and

* Engineering, March 8, 1867.

opened afterwards so as to admit a fresh portion of air, and by this means a constant blast is kept up. The nozzle of the bellows is inserted into tubes of clay, which are put into the furnace at the bottom corners of the temporary wall in front; the furnace is filled with charcoal and ignited at the entrance of the nozzle, the ore is then placed on the charcoal and covered with the latter. Ore and fuel are thus supplied, and the bellows are urged for three or four hours, when the process is stopped—the temporary wall in front is then broken down, and the bloom is removed from the bottom of the furnace. This then is beaten by a wooden mallet so as to separate from it all the scoriæ; while still hot it is cut through the middle so as to present the interior of the mass. This is now iron, and, in order that it may be converted into steel, the natives cut it into such pieces as may be conveniently packed into the crucibles, which are made of refractory clay, mixed with a large quantity of charred husk of rice. It is charged with one pound of iron, one pound of wood, covered with a few green leaves. The mouth of the crucible is then closed with tempered clay so as to exclude the air. The wood used is *Cassia auriculata*, and the leaf that of *Asclepias gigantea*, or the *Convolvulus laurifolius*. Twenty to twenty-four of the crucibles, as soon as the clay plugs are dry, are built up in the form of an arch in a small blast furnace. These are covered with charcoal and subjected to a heat urged by a blast for two and a half hours. The crucibles are now taken out and allowed to cool, after which they are broken and the steel is found in the form of a cake, rounded by the bottom of the crucible.

The following is an analysis of the wootz, or Indian steel, taken from Percy's work on Iron and Steel:—

Carbon combined	.	.	.	.	1.333
Carbon uncombined	.	.	.	.	.312
Silicon	.	.	.	.	.045
Sulphur	.	.	.	.	.181
Arsenic	.	.	.	.	.037
Iron by difference	.	.	.	.	98.092
					<hr/>
					100.00

Specific gravity of the above, 7.727 at 62° F.

The following observations on the specific gravity of wootz were made by Dr. Pearson:—

1. Wootz	7.181
2. Another specimen of wootz	7.403
3. The same, forged	7.647
4. Another specimen, forged	7.503
5. Wootz which had been melted	7.200
6. Wootz which had been quenched while white hot	7.166

The following may be interesting in this connection:—

On the Indian Method of Working Iron and Steel for the Damascus Gun Barrels and Sword Blades.

BY CAPT. MICHAEL E. BAGNOLD, OF BOMBAY.

(From the Transactions of the Society for the Encouragement of Arts, Manufactures, and Commerce.)

On the Damascus Gun Barrels.—Those made at Bombay, in imitation of Damascus, so much valued by the Orientals for the beauty of their twist, are *manufactured of iron hoops, obtained from European casks, mostly British*. If not rusted, they are exposed to moisture until they are sufficiently prepared for welding. They are piled in lengths of about twelve inches, one or one and a half inches high, laying the edges straight, so as not to overlap each other; a longer piece is then so fitted as to return over each end and hold the whole together in the fire; it is then heated to a welding heat, and drawn out to one inch wide and one-third of an inch thick; it is then doubled up in three or more lengths, and again welded and drawn out as before, and this repeated to the third or fourth time, according to the degree of fineness of twist desired. The bar is then to be heated one-third of its length at a time, and, being struck on its end, is flattened the contrary way to that of the stratification; this brings the wire or vein outwards upon the strap. The barrel is forged as usual, but much more jumping (or upsetting endways) by striking the barrel against the side of the anvil, when at a welding heat, to render the twist finer. The most careful workmen always make a practice

of covering the part exposed to the fire with a lute composed of mud clay and the dung of cows or horses, in order to guard against any unnecessary oxidation of the metal. When the barrel is completed, the twist is raised by laying the barrel, from one to five days, either in vinegar or a solution of the sulphate of iron, until the twist is raised—this process is called the wire twist.

To produce the *curl*, the bars or scraps are drawn about three-fourths of an inch square, and twisted some to the right and some to the left; one of each sort is then welded together, doubled up, and drawn out, as before described—and according to the skill of the workmen will be the intricacy of the twist.

Sometimes to save time an artist will rough file an English barrel, and spirally wrap a piece of Damascus iron around it and along it, and then weld.

A native artist never works with pit coal under any consideration; charcoal from light wood forms his only fuel.

Damascus Sword Blades.

Some make a pile of alternate layers of softer and harder cast steel, with powdered cast iron mixed with borax sprinkled between each layer (the soldering steel or iron with cast iron and borax, and welding afterwards, seems to be an Eastern practice). These are drawn out to one-third more than the length of the intended blade, doubled up, heated, twisted and reformed several times (the twist is brought out as in gun barrels).

Some swords are forged out of two broad plates of steel, with a narrow plate of good iron welded between them, towards the back, and thus leaving solid steel for the edge, of a considerable depth. Others prefer to make them of one plate of steel with a lamina of iron on each side of it to give strength and toughness.

Swords of this kind were tempered with the following compound, and with considerable effect:—

The Hardening Composition.—The blade was covered with a paste formed of equal parts of barilla, powdered

egg shells, borax, common salt, and crude soda heated to a moderate red heat, and just as the red was changing to a black heat, quenched in spring water.

From information from the workmen it appears that Damascus obtains all its steel from the upper part of the Decon, where it is called Indian steel.

Steel from Malleable Iron, Melted. Mushet's Steel.—David Mushet obtained a patent in 1800 for a process of manufacturing cast steel. It consists in fusing malleable iron in the form of bar or scrap, or iron ore, when sufficiently rich and pure, in crucibles with a certain amount of carbonaceous matter. The quality of the steel will vary according to the amount of carbon—less carbon will make softer steel and more carbon will make it harder.

It is said that if $\frac{1}{140}$ to $\frac{1}{150}$ of the weight of iron in charcoal be fused with the iron, a product will be obtained between malleable iron and steel. This can be welded and slightly tempered.

It possesses great strength and tenacity, and admits of a high polish. If the above amount of carbon is diminished, the iron becomes more and more red-short, and loses its weldability. When $\frac{1}{300}$ th of the weight of iron is carbon, it appears to have little or no effect on the iron.

This method has been attempted at various places in country and elsewhere. Mr. Jas. Park, of Pittsburg, of the firm of Park, Brother & Co., Black Diamond Steel Works, whose experience is practical and thorough, writes us upon this method, which we suggested some time ago as an experiment, as follows: "I have tried the melting of good malleable iron and good charcoal pig with unsatisfactory result, the production being a very poor unmerchantable quality of cast steel. *Good* cast steel cannot be made without first producing from good quality of pig iron (charcoal) good malleable iron, in the production of which, unless the iron is carefully and well worked with the use of charcoal fuel, the resulting cast steel will be bad. I find by careful experiments, that the importance of carefully working the charcoal

pig into malleable iron, with the use of charcoal fuel, cannot be overrated. A very small piece of the best quality of charcoal pig iron (even an ounce) dropped into the steel in the crucible will destroy the quality. To melt malleable iron alone would take about 4200 degrees, and be very expensive, as it would be too high a heat to allow the furnaces or crucibles to last for any reasonable time. Steel melts at 2800 degrees, and this we find as high as crucibles and furnaces should be subjected to."

This presents the difficulty which at the time we did not fully realize, nor can we yet, in so broad a sense as that communicated to us in the above, as we shall see further on in treating of the new steel lately made with chromate of iron.

Another experiment, which we may as well state here, in some considerable measure elucidating the rationale of the formation of steel, is connected with the cementation process. We suggested that, perhaps, the hammering of the bar before cementation might have a tendency to modify the hardening, by increasing the closeness of texture and thus increasing the hardness. Mr. Park writes as follows:—

"I tried the experiment with no good result. The bars, after being hammered, resist taking up carbon in the converting furnace, and are not, in that condition, as good for melting as rolled bars of iron.

One experiment made, was to heat the bars, before being hammered, in a charcoal fire—the experiment satisfied me that nothing was gained by this expensive treatment."

There is a metal lately introduced under the title of "homogeneous metal." As this metal is of importance in some of the parts of important machinery, and is a steel of a low amount of carbon, we shall speak of it in this place. The homogeneousness of the metal is due to fusion. A specimen contained .23 per cent. carbon. The relation between the iron and carbon (*i. e.*, exclusive of O .334 per cent. of Si, S, P, and Mn), is 99.206 : 0.230, or about $\frac{1}{4\frac{1}{3}}$ ths of carbon and less than the smallest

proportion of carbon given by Mr. Mushet; but his proportion was theoretical, and only a direction of procedure, and not an actual found amount. The term was used for it in a patent granted Jos. B. Howell, for making steel from mixture of iron scale "in addition to the ingredients in common use for making cast steel," which is practically "meagre and unsatisfactory."* Dr. Percy considers that, in principle, there is no difference between the ancient Hindoo method of making wootz and Mushet's process.

American Uses of this Metal.

The following remarks will appropriately be made upon the uses and the qualities of this metal as made in our own county, and, as Pittsburg, Pa., is the great Sheffield of America, we shall notice some experiments made in the use of this low grade of steel. Last Jan., 1868, we were shown by Mr. James Park, of the Company, hereafter mentioned, a steel tube, or pipe, about two and a half inches calibre and of about three-sixteenth thickness, in a section of five inches, which was by one blow of the hammer reduced in length to about seven-eighths inch without the slightest crack. This same experiment was tried by the side of some excellent English homogeneous or steely iron, perhaps not of the best reputation at home but of good reputation here. The latter section, of the same size in all respects, suffered several small ruptures by the same blow. Both pieces were placed upon the same block and struck by the same blow. This iron is of great importance in the formation of locomotive engine fire-boxes and in other exposed parts of the engines. The following, under the form of an editorial in the *Pittsburg Gazette*, May 28, 1868, gives a sufficiently satisfactory history of late attempts to make and use the above-mentioned kind of steel.

Within a few years the manufacture of steel has become one of the most important in this city, the annual product now

* Dr. Percy, p. 777.

reaching five millions, without including the value added to much of it by being wrought into tools, agricultural implements, and other useful forms. Besides the rapidly increasing demand for the many purposes for which it has already been used, it is constantly being applied to new uses; and while iron is supplanting other materials of construction, steel is encroaching on the domain of iron. Its greater strength has always afforded hopes of its proving fitter than iron to resist heavy strains; but the supposed difficulty of producing uniformity of quality, long prevented its being trusted by engineers. Latterly this difficulty has been so completely overcome, that our best manufacturers are able to vary the quality of their steel to suit any purpose for which it may be required, so that quite a vocabulary of terms is used to denote the numerous varieties. One of these, usually called "homogeneous metal," contains much less carbon than other steel, and so occupies a middle position between wrought iron and cast-steel, partaking of the qualities of both. This is so even in the process of manufacture. It is melted with much more difficulty than steel, but with less than iron, the fusibility of steel depending upon the amount of carbon it contains. For this reason its production requires more skill than higher grades of cast-steel, and is attended with greater expense; crucibles which would last for several heats with the one are often destroyed by a single charge of the other. In malleability and ductility homogeneous metal is equal to iron; it welds nearly as well; is tougher both hot and cold; has much greater tensile strength than iron; and is free from the brittleness of highly carbonized steel. These qualities render it so superior to iron that it is now substituted for many purposes for which the higher grades of steel are utterly unfit.

Its use in the construction of boilers should be especially interesting to the public, where it so involves the security of life. For this purpose it might appear at first sight as if great strength were the most necessary quality, and such, indeed, was the belief when it was first used for boilers. Steel boiler plates were then required to have a high tensile strength, and this was obtained in the readiest manner by making them hard; and invariably where this was done failures resulted, the plates often cracking in punching, riveting, or calking, and thus preventing a worse catastrophe. John Brown & Co., of the Atlas Works, Sheffield, one of the most noted firms in England, for a time signally failed in this way, so that now their manager, William Bragg, whose reputation as an engineer gives great weight to his opinion, states that no steel of more than 75,000 pounds tensile strength should be used for boilers, and in this

opinion he is sustained by the London *Engineer* and other high authorities. On the other hand, the British Admiralty retain their original specification requiring a minimum tensile strength of 80,000 pounds of steel used for armor plates and for steel vessels, and make no specific requirement of a certain degree of ductility. The disastrous results of this adherence to exploded notions have been deprecated by English engineers, but, as yet, to no purpose. Steel-makers easily fulfil the requirements of the government specification by furnishing a highly carbonized, and therefore hard and brittle steel, for purposes where the opposite qualities are imperatively necessary. Vessels so made would quickly break to pieces upon rocks, where those made of soft, ductile, and flexible plates might be battered out of shape before rupturing the plates or starting a serious leak. So, too, locomotives with boilers made of such plates have plunged over precipices or into each other without explosion, because the material yielded to the violent strains—stretching or bending, but never breaking.

Now for the rationale of all this. To make it obvious to all, let us take the instance of two steel springs, one tempered so hard as to be brittle, the other soft and elastic. The first is more rigid and will support a much heavier weight than the other. In this sense it is stronger. Vary the test by striking a heavy blow on each. The strong, rigid, highly tempered spring snaps off, while the more mild tempered yields to the blow, and then, by its elasticity, returns uninjured to its former shape. Again, bend both, and the stiff spring breaks before the other is at all strained. The same difference obtains in boilers, and is aggravated by other causes. Among these are the unequal strains produced by irregularities of riveting. The soft, ductile steel, yields to these without being unduly strained. The hard resists until it is broken, or the offending rivet is torn away. Unequal expansion and contraction also operate destructively upon the more rigid boiler, while that of softer material is not endangered. Many mysterious explosions have been so caused. When cold water is rapidly injected into a highly heated boiler it tends to the bottom, cooling that part while the top is kept hot by the steam. In a boiler thirty feet long a reduction of one hundred degrees of heat at the bottom will cause it to contract nearly one-fourth of an inch in length; but the boiler heads being kept apart by the still expanded portion above, the bottom plates are distended, so as to rupture them if too hard, or to elongate them without danger if sufficiently ductile. Thus in every way the highly carbonized steel is at a disadvantage. Here the battle is not to the strong, unless that strength coexists with a mild and flexible disposition.

Not that we decry great tensile strength as in itself a fault. In this we agree with the opinion of an English authority, J. F. Smith, Esq., C. E., manager of the Barrow Iron and Steel Company's works. He says: "A higher coefficient of rupture than forty tons is unadvisable in the present state of manufacture, as, although that or a far higher coefficient may be procured, it is so at a more than proportionate loss of elongation, *i. e.*, toughness in the steel." And he rightly considers a moderate ultimate limit of strength, with a large elongation, as that which should be sought by the engineer employing steel in his structures.

Commenting on this the *Mechanics' Journal* says: "In this we ourselves quite agree, although at the same time urging upon the steel maker that his business is to exalt the breaking standard to the highest point he can, while keeping it combined with a large, at least a sufficiently safe, coefficient of elongation. We saw with some surprise, specimens of bolt steel which had been pulled asunder under a strain of thirty-two tons per square inch, and the ultimate elongation of which was as much as one-sixth the unit, or two inches to the foot, a degree of toughness which we did not previously believe procurable with Bessemer, or, indeed, any other steel of that tensile strength."

Now we have recently seen several pieces of Pittsburg steel tested, which bore a much higher strain than this, and were elongated three inches to the foot. These were made by Park, Brother & Co., of the Black Diamond Steel Works. Yesterday we noticed the testing of a boiler made of that variety of their steel called "homogeneous metal," which bore more than 720 pounds, pressure per square inch, equivalent to 74,000 pounds, tensile strain, without bursting; while the plates stretched enough to increase the circumference nearly three inches. By this trial the qualities of steel recommended for boilers, by the best engineering authorities, were shown to have been combined in that which was subjected to it.

The experiments alluded to are more particularly described in the following remarks furnished us by a gentleman who is well acquainted with steel manufacture, and was present at this trial. They were given in the *Evening Chronicle*, but in somewhat different form:—

The plates are one-fourth of an inch thick, and the boiler is seven feet in length and thirty-eight inches in diameter. The first test to which the boiler was subjected, was witnessed by a number of persons interested in such matters, including the government inspectors. The test was made in the manner pre-

scribed by the government regulations, hydrostatic pressure, and was satisfactory in every respect. On that occasion a pressure of 665 pounds to the square inch was applied, and on a subsequent trial a pressure of 820 was gained. Under such strain the joints leaked to a considerable extent, and the experiments were suspended for the purpose of closing up the leaks that the full strength of the plates could be definitely determined.

Since that time canvas was placed inside the boiler, and such other arrangements made to prevent leakage as suggested themselves, preparatory to another test, which was made yesterday. The experiments yesterday afternoon were conducted at Messrs. Carroll & Snyder's establishment, and attracted a large number of machinists, manufacturers, and others. At three o'clock the pumps were set in motion, and the water forced into the boiler with great rapidity. Gradually the indications on the gauge increased, until 400 was attained. The seams now began to leak slightly, and when 500 was reached the leakage had been increased considerably, there being no signs yet, however, that the boiler was about bursting, or any of its plates giving way. At 540 it was found necessary to take off the pressure and repack the seams, when the pumps were again set to work, and a pressure of 560 pounds to the square inch was applied. This was the utmost that could be attained at the time, and consequently at this point the experiment was abandoned, to be resumed when better facilities for making the test shall have been procured.

These tests, while they leave the definite strength of the plates undetermined, demonstrate the fact that steel, such as that made at the Black Diamond Works, can be used for the construction of boilers, and that boilers made from such material will withstand almost any pressure that can be applied. The importance of this fact is too obvious to require any argument, and we cannot but congratulate the Messrs. Park, Brother & Co., on the success which has crowned their efforts in this direction. The Messrs. Carroll and Snyder are also entitled to credit for the superior skill which they have exhibited in the construction of the boiler. Another test will be made in a few days, by which time it is expected that pumps can be procured of sufficient capacity to burst the plates.

Tensile Strength of Cast Steel Boiler Plates.

The following is an official copy showing the tensile strength of cast-steel boiler plate, from the works of Hussey, Wells &

Co., Pittsburg, Pa., as determined June 16, 1868, at the Navy Yard, Washington, D. C., for the Treasury Department—

Diagram of sheet.			No. of specimen.	Dimensions at point of rupture.	Area at point of rupture.	Actual breaking weight.	Tensile strength per square inch.
1	2	3	1	1.5×.26	.39	35.700	91.528
			2	1.5×.26	.39	35.850	91.923
			3	1.5×.26	.39	36.925	94.679
			4	1.5×.26	.39	36.575	92.782
			5	1.5×.26	.39	36.900	94.615
4	5	6	6	1.5×.26	.39	38.000	97.435
						Mean,	93.995

The flanging qualities of this plate were tested and proved to be very superior.

BENJ. CRAWFORD,
Special Agent Treasury Department.

It must not be supposed from the above that the use of steel for this purpose and for associated purposes is entirely novel, for we are assured* that there have now been at work for some years on the Maryport and Carlisle Railway several locomotives having steel boilers, steel fire boxes, and steel tubes. Steel is also largely used in the construction of the remaining parts of the engines, the tyres, piston-rods, motion bars, &c., being of that material. The boilers were built by Messrs. Daniel Adamson & Co., of the Newton Moor Iron Works of Hyde, England, and the plates composing them are connected, when necessary, by angle-irons. The same firm is making some very large Bessemer steel boilers for a sugar bakery in London. They are intended to work at 100 lbs. steam pressure, and are 8 feet in diameter, and formed of $\frac{7}{16}$ inch plates. Each ring is formed of a single plate, 26 feet 6 inches long and 3 feet 6 inches

* Colburn's Engineering, 1867.

wide, giving but a single longitudinal seam. The rivet holes are drilled. The plates are made by the Bolton Iron and Steel Company. The 6 feet 6 inches Bessemer steel boilers made by Mr. Adamson in 1861 for Messrs. Platt, Brothers & Co., of Oldham, are working at a pressure of 75 pounds, the plates being but $\frac{1}{4}$ inch thick.

After Mr. Ramsbottom started his thirty-ton duplex hammer (1867), he made in a few weeks about 20 steel cranks each from a plain flat slab, the "throws" being sawn out by a circular saw, and the middle portion of the shaft then twisted. The crank is then nearly finished by circular cutters, instead of entirely by a fixed tool in the ordinary manner.*

Steel from Cast Iron, Melted.—I. Fining with charcoal. II. Puddling. III. Decarbonizing by forced air or vapor.

I. FINING WITH CHARCOAL.—In this case, the hearths are similar in shape to the puddling hearths, generally smaller, surrounded with cast-iron plates. A blast is used and less inclined than in making malleable iron. The cake or lump of metal is kept covered with liquid cinder. Skilful work is required, but regularity of formation is considered impossible—steel being made at one time, and iron at another. The first cake is called raw steel, and is refined by being heated in charcoal, in the furnace again, and with a blast carefully regulated. The bottom of the hearth is laid with fine-grained sandstone. There are various modifications, but all are radically the same.

II. PUDDLING.—The general principle upon which this depends is the decarbonization of cast iron and the stoppage of that decarbonization at the proper point. While, however, this is the general principle, there are important accessories to the practice which we shall mention.

Puddled steel has been attempted and successfully made as far back as 1835, by Schlegel and others, who obtained a patent, but it was not successfully brought

* Engineering, 1867.

into use until 1850, and during the writer's visit to the International Exhibition in London, 1851, a large variety of specimens were on exhibition made from charcoal iron and from Welsh pig.

The important accessories to the principle above stated may be found in Riepe's process. In this process the ordinary puddling furnace is charged as usual, heated till fusing begins; damper lowered to temper the heat, and then from 12 to 16 shovelful of iron cinders, discharged from the rolls or squeezer, are added to say 280 lbs. pig iron. The whole is melted down—puddled uniformly, with a mixture of black oxide of manganese (Mn O_2), common salt and dry clay, mixed and ground together previously. After some minutes the damper is opened—40 pounds of pig arranged near the fire-bridge on a bed of cinder previously prepared, and when these pigs begin to trickle down and the blue spirts appear on the other melted metal, these pigs are raked down, and the whole thoroughly mixed. The mass begins to swell, and the "grains" appear penetrating upwards through the melted cinders. The damper is three-fourths shut, and all puddled under the cinder. During this process the air part of the furnace should barely exceed in temperature that necessary for welding; the blue jets gradually disappear, and the grains unite, and all appears of a "cherry redness." If these precautions are not attended to strictly, the iron becomes only malleable, or there is steel of irregular character. At this stage the fire is stirred, that heat be kept up for subsequent operation; damper is then closed, and a part made into a ball, the rest kept covered with cinder. This is worked up in the roll, and then another balled, which is taken out, and so on to the close. When pig, made from sparry iron, is used, only 20 pounds, instead of the 40, are used. Very good puddled steel has been made by this process. But the whole art is in working out the carbon only to a certain point under a lower temperature than in puddling iron, and with great care in the manipulation. The iron to be used appears best when of a bright even gray, or low dark gray, melted at a moderately

strong heat; afterwards the temperature is immediately reduced, keeping the iron in a low fused state. It is then rabbled, carefully mixing the ordinary puddling amount of cinder previously thrown in. A *special point* is the rabbling under as low a state as the iron will permit, as a high melted state prevents the escape of CO formed at the expense of the O of the iron-oxide of the cinder, and a too low state prevents the mixing of the cinder, and the homogeneity of the steel.

Mr. Clay states that the tensile strength of puddled bar steel is 43 tons to the square inch, while that of the puddled iron bar is only about 20 tons.*

Spiegeleisen is largely used in the process, as it renders the cinder more fusible in the balling process, so that it can be the more readily expelled in the agglutination of the process, and in the shingling. Refined metal (pig) loses in the process of refining from $\frac{1}{2}$ to 1 per cent. of its carbon, and therefore requires a higher temperature in the puddling process, and hence it is exceedingly difficult to run it successfully in puddling for steel. Common Welsh pig iron, containing a large per cent. of sulphur, cannot be used in making puddled steel.

A difficulty experienced in puddled steel is the lack of easy weldability; but this has been remedied by fusion, and this subsequent fusion has been carried out on a very large scale by Krupp, of Essen. No amount of pressure has as yet effected homogeneity in the mass equal to that which follows upon subsequent fusion.

The rationale of the process is well exhibited in the following analyses given by Dr. Percy from Mr. Parry's paper upon the subject.†

	Puddled Steel.	Pig Iron.
Carbon . . .	0.501	2.680
Silicon . . .	0.106	2.212
Sulphur . . .	0.002	0.125
Phosphorus . . .	0.096	0.426
Manganese . . .	0.144	1.230
Iron (by difference) .	99.151	93.327
	<hr/> 100.000	<hr/> 100.000

* Dr. Percy, p. 794.

† Dr. Percy, p. 797.

The large proportion of silicon in the pig iron indicates that the carbon must have existed almost wholly as graphite. (Percy.)

Composition of the cinder produced by puddling steel:

	I.	II.
Silica	26.0	23.5
Protoxide iron	55.9	68.0
Protoxide manganese	10.5	8.4
Alumina	6.8	3.3
Lime	0.6	
	<hr/>	<hr/>
	99.8	101.2

I. By Schnabel, from the Lohhütte, near Siegen, spec. grav. 3.643

II. By the same and from same locality, spec. grav. 4.127

A number of what are called, in this country, *medicines*, or in England, according to Dr. Percy, *nostrums* and “patent powders,” have been used both in making malleable iron and steel. They are generally composed of manganese, common salt, prussiate of potash (ferrocyanide of potassium), and sometimes of soda and lime, when of any real use—sometimes litharge is also used—and we have found some decided benefit resulting from the use of permanganate of potash and nitrate of soda. The mixture is divided off into paper parcels, and thrown in consecutively, and puddled into the iron, sometimes with good effect, and sometimes with no effect. Chloride of sodium, manganese, and nitrate of soda seem to eliminate much of the sulphur and even of phosphorus, and thus prepare the iron more fully for the purpose of making good steel.

Mr. Heaton, of Langley Mills, places nitrate of soda at the bottom of the crucible, covering it with a perforated iron plate. The iron to be purified is placed above this, the melted nitrate diffusing itself through the melted metal, completely desulphurizing and dephosphorizing. Experiments at this place, with cinder iron which was utterly useless for the Bessemer process has produced steel-iron of the finest quality. It

is said that a large Staffordshire firm is preparing to make the experiment on a large scale.*

Many nostrums are of no apparent use, and therefore care and science are required to form a proper judgment as to the benefits to be expected from such mixtures.

Under the general head of puddling cast iron into steel, may be mentioned the *Uchatius Process*, patented in 1855. The fused pig iron is granulated into uniform shot, by being poured upon a large stone or circular plate, turning rapidly horizontally (2000 revolutions per minute) under water. The centrifugal force sends the melted metal off from the wheel, and in uniform sizes of so-called shot, and this is melted in crucible or in the puddling furnace, with pulverized sesquioxide ore, "or with other substances capable of yielding oxygen." The quantities of pig iron and of oxide of iron must be carefully adjusted, and the sizes of the shot must be uniform, else the steel becomes uneven and irregular in quality.

Malleable cast iron is the result of a process of decarbonizing cast iron by a process of cementation by means of hematite (sesquioxide), whereby the hematite, by imparting a part of its oxygen to the carbon in the cast iron, at a red heat, forms CO, and thus extracts the carbon from the castings. When this decarbonization is carried forward at just such a degree as to leave the proportion of carbon necessary for steel, and nothing more or less, steel is the result. The invention is attributed to Lucas in 1759.

"Early in the last century, Reaumur published the fact that he had been very successful in making steel, by melting cast iron and introducing pieces of wrought iron into the cast iron, until the mass thus resulting had been reduced from cast iron to steel. He writes, "I have mixed sometimes a quarter, and sometimes a third of iron with pig iron."† It is interesting that a patent was taken out in the year 1867, for this identical process, by a steel manufacturer in our own State.

* Quarterly Journal of Sciences, London, July, 1867.

† L'Art de Converter le Fer Forgé en Acier, 1722, p. 256.

III. DECARBONIZATION BY FORCED AIR OR VAPOR. *Process by J. Gilbert Martien, of Newark, N. J.*—This gentleman received a patent while in England in 1855, for the invention of improvements in the manufacture of iron and steel. His process is closely related to the celebrated Bessemer process. According to this method it is claimed that the iron can be purified by means of atmospheric air, or steam, or vapor of water, while the iron is in a liquid state, in a blast or refinery furnace, the atmospheric air, steam, or vapor of water is introduced from below, so that it may penetrate and search every part of the metal before it congeals; the impure particles, such as silicon, sulphur, and phosphorus, are carried off in the form of gases. According to Percy, the essence of this patent seems to consist in exposing a stream of molten pig iron, *in its course*, to the action of jets of atmospheric air, of steam, or of a mixture of both, introduced at the *bottom*, or *below*, the surface of the liquid metal. It is objected to the synonymous use of the terms atmospheric air, steam, or vapor of water, implying, as they do, like effects, that there is thereby conveyed a wrong impression. Air, by oxidizing both carbon and the iron of the molten metal, not only maintains, but increases the temperature, while, on the contrary, steam will decrease the temperature and tend to solidify the molten metal.

Bessemer's Process.—In October or November, 1855, about three months later than Mr. Martien's discovery, Mr. Bessemer received his first patent. The invention consists in "forcing currents of air or of steam, or of air and steam, into and among the particles of molten crude iron, or of remelted pig or refined iron, until the metal, so treated, is thereby rendered malleable, and has acquired other properties common to cast steel, and still retaining the fluid state of such metal, and pouring or running the same into suitable moulds. The molten metal is run into crucibles previously heated, which are contained in a rectangular furnace. Each crucible has a tap-hole through which the metal is tapped into moulds. Steam, with air, or separately, and by prefer-

ence raised to a high temperature, is forced downwards through a pipe which descends to the bottom of each crucible. Steam, as stated before, *cools the metal*, but air causes a rapid increase in its temperature, so that the metal passes from a red to an intense white heat, and when sufficiently decarbonized is tapped off. The essence of this invention is the *increase of temperature by use of common air*.

The second patent of Bessemer, which was for the *reducing vessel*, was obtained in December, 1855. It was of a spherical or egg form, and was made of cast or wrought iron lined with fire-brick. The vessel is suspended on axes so that it may be turned and the metal poured through a lid into an iron mould so as to form ingots *suitable for puddling*.

Another patent was granted Mr. Bessemer, Feb. 12, 1856. According to this, crude iron, or remelted pig or refined iron was converted "into steel or into malleable iron *without the use of fuel* for reheating or continuing to heat the crude, molten metal. This was effected by forcing into and among the particles of a mass of molten iron, currents of air or gaseous matter, containing or capable of revolving sufficient oxygen to keep up the combustion of the carbon contained in the iron till the conversion is accomplished." In this patent, steam was not claimed as a substitute for atmospheric air. There were a number of other patents granted to Mr. Bessemer, but the most important have been mentioned, and we need not refer to them now, if we except one, that of Mr. Robert Mushet, dated September 22d, 1856, to whom Mr. Bessemer is deeply indebted.

It consists in adding spiegeleisen to Bessemer's decarbonized metal, while still in a state of liquidity. The advantage gained by this patent is to decarbonize the iron to any extent, or, in other words, have perfect control over decarbonization of iron. The carbon being a fixed quantity in the spiegeleisen by its addition to the Bessemer's decarbonized metal, the amount of carbon can always be known with certainty.

In the Bessemer process, the iron before being converted

into steel must be almost entirely free from phosphorus and sulphur, for a very small quantity will prevent the formation of steel. Nearly all our ores contain more or less of these foreign elements, and hence the iron will not be free from them. So that, until by other means the iron, which is to be converted into steel, is freed from these substances, the Bessemer process is practically worthless in this country, except in special regions.

The following is an analysis of a specimen of Bessemer iron, by Mr. Abel, showing its freedom from these foreign elements:—

	Per cent.
Carbon, graphitic	0.00
Carbon, combined	minute quantity
Silicon	0.00
Sulphur	0.02
Phosphorus	trace
Manganese	trace

The following graphic description of the whole process through its consecutive steps and with all the collateral interests, we think will sufficiently present the general management of the Bessemer process:—

Two ten-ton converters, capable, on a push, of pouring a twenty-four-ton ingot, to which may be blown every two hours and a half, or as fast as the metal can be melted, and the ingots get out of the way—converters capable of turning out 5000 tons of steel per month—take up really less room than is occupied by the cupolas in many a country iron foundry, and, when not in action, are hardly more pretentious in appearance. The hematite pigs are now melting in the large reverberatory furnaces behind the converters, and the spiegeleisen which has a little furnace to itself, is already on the boil. The casting-pit forms an amphitheatre and the hydraulic hoist is rising and falling as the ingots from the last cast are lifted out to be sent away on trucks. The converters are being heated—the foreman says warmed—by the combustion of half a hundred weight of coke [bituminous coal at Troy Works] under the action of the blowing engines, working at quarter speed, and are shooting forth a bright red column of flame up the chimney. Occasionally the hydraulic gear is turned on, and the great vessels which do not look half their real size, swing on their trunnions in a manner which suggests—and the suggestion is heightened

by their unwieldy and analogous form—the genuflections of the performing elephants. Unlike nearly all other great metallurgical operations or those mechanical operations, hardly less formidable, which follow them, the Bessemer process appears to require but few attendants. There are less than a dozen men about, and half of these to be sure are mere laborers, employed to get the ingots from the last cast out of the way. At last, however, the blowing engines, which work almost as silently as the ventilating apparatus of the houses of Parliament, or the chimney draft of the reverberatory furnaces just outside quicken their speed, and the blast rises on the gauge from 5 lbs. to 15 or more per square inch. The converters are again turned completely over upon their trunnions and drop the glowing remnants of their breakfast of burning coke, and immediately and stately rise to their proper positions. Half a minute later, and the furnaces behind are tapped. The metal comes pouring, ten tons together in a river of fire, with its banks deeply bedded in sand, and the huge converter drinks in the running stream. As the melted iron flows on it scintillates in a shower of yellow sparks each flashing its wings of consuming silicon and carbon—the characteristic spark of cast iron, well known to every founder.

The converter now stands upright and the full blast is on. First of all the rushing air seizes upon the impurities of the iron [not all the impurities, as sulphur, phosphorus, &c., but carbon particularly] and carries them off in a blazing column of flame. The rush is tremendous. A pillar of fire more than two feet in diameter points straight up the chimney. Beyond its own dull roar is heard the beat of the non-condensing blowing engines which send a hundred blasts a minute of [exhaust] steam into the air through a pipe high aloft. The flame increases in brilliancy, and lights up the brick walls and the amphitheatre below with a glare well known to blast furnace men and to steel founders, although it is seldom or never seen in iron foundries or rolling mills.

Now for the spectroscope, a little instrument in shape like a sea glass, and showing through its narrow aperture for light a beautiful field of iridescent colors. The whole column of flame seems changed into a short section of a glorious rainbow, with red, bright orange, green and purple spread out upon a broad space apparently three feet wide, although the luminous aperture is hardly the breadth of a hair. There are dark lines across it, and these are streaks showing the impurities of the escaping silicon and carbon. One by one these bands disappear and a fine prismatic display remains. The blast continues but for a few minutes, and the flame changes to almost un-

earthly light. The last traces of carbon are flying away in the blasts, and it is not unlikely that the oxygen of the air is already at work upon the iron itself. The practised eye of the manager, without any aid from the spectroscope, shows him when the blast is to be turned off, for the "blow" is not to be carried too far, and then the huge converter bears upon its stout trunnions and under the invisible force of the hydraulic gear, to receive the finishing dose of spiegeleisen, the "looking glass iron" of the Germans, whose name it still bears in England, and which the Hull custom-house officer once stopped in its importation as silver. This, we need hardly now explain, is merely pig iron changed with a proportion of manganese, a proportion less than on the extraordinary natural compound of iron, zinc, and manganese known as franklinite, and far less than in the artificial compound now known as ferromanganese. This dose of spiegeleisen accomplishes two ends. It restores a definite proportion of carbon to the charge of iron already completely decarbonized, and its contained manganese, which is one of the most highly oxidizable of metals—ranking below sodium—searches out and takes up any oxygen which may have combined with the iron during the operation of blowing. In it goes, and the pig iron of this morning is now Bessemer steel. There is no blowing after the addition of the Spiegel. It mixes, by a natural process of diffusion, as rapidly as brandy mixes with water. This question of complete mixture was once thought to be the doubtful problem in the Bessemer process. But the doubts were needless; for the mixture is evidently one ordained by nature, and wholly independent of the act or assistance of man. The proof is that, after a few seconds have been allowed for complete mixture, the ingot, after pouring, is equally carbonized throughout. In other words, it may be cut up in any number of pieces, and each piece tested for carbon, will give the same fraction of one per cent., the proper proportion for steel rails being from 0.4 to 0.5 per cent., the latter being that specified by Mr. Berkeley in his contract for rails for the great Indian Peninsular Railway.

The converter tips again over a ladle, large enough for a full grown man to swim in, and which has swung silently round upon a radial arm, impelled by an invisible force, to receive charge. Out comes the silvery steel. There are sparks now, and thousands of them, but how different from those of a quarter of an hour ago! They are clear white globules of incandescent steel, without trace of the yellow corruscating astral shower of melted iron when thrown into the air. The great ladle is now brimming, and the converter may rest. There is a semi-circular row of cast-iron ingot moulds and each receives

its fill in turn, as the ladle, counter-weighted at the opposite end of the hydraulic arm, swings to it, and is tapped by means of a fire clay valve at the bottom. The ingots "set" in a few minutes, and they might, indeed, be turned out and hammered at once, as is the case in Crewe.

How different is the converter of to-day from the clay colander with which Mr. Bessemer made his early and astonishing experiments in Baxter House, now, we believe, demolished, for the works of the Midland Railway! Indeed, clay would not stand the tremendous heat of liquid steel, at any rate not beyond two or three rounds, as is the case with the fire clay crucibles still used in pot-steel melting. Ganister, a siliceous stone found in abundance near Sheffield, where it is broken and used for road-metalling, was soon found to be the proper material for lining. It is crushed to powder, and damped, and the converters are lined with it from six to nine inches in thickness, the lining being rammed in around a wooden core, and then quickly glazed by a hot coke fire made in the converter, which fire is continued to complete baking. These linings stand, often, a hundred rounds, equal in the larger vessels to a make of a thousand tons of steel. The blast, which is led through the trunnions and down the side of the converter, enters through the bottom, through a series of fire-clay tuyeres. In the larger vessel there are perhaps twenty of these tuyeres, each having a dozen holes. Sometimes the iron burns out a tuyere during the operation of blowing. The converter is tipped upon its side at the moment when a great rush of air and loss of blast show that this accident has happened, and the whole bottom of the converter is taken off, a new tuyere put in, the bottom made good, and the blast turned on, all within a very few minutes, and without real injury to the charge from the interruption. We have been told that this has actually happened as often as three times during a single blow, and that sound ingots were nevertheless poured. The tipping converters, and the admirable applications of hydraulic force for performing their every movement and those of the ladle, as well as for lifting the ingots out of the way, all show the elegant ingenuity of their inventor, Henry Bessemer, who does everything differently from, and better than, any metallurgical engineer before him. The blowing engines are his, too, with their "breathing valves," simple rings of India-rubber surrounding the blowing cylinders, near their ends, with air holes beneath; and they work silently, and are durable at all speeds, and under the great pressure of from 15 lbs. to 20 lbs. per square inch, a pressure necessary to overcome the ferrostatic "head" of a column of a melted iron 5 feet to 6 feet deep within

the converter. The engines and the hydraulic gear are controlled by an attendant standing upon a rostrum, or within a sort of judge's desk, commanding the whole scene of operations. Wonderful process! It is giving us steel of extraordinary quality for hardly more than the price of the better marks of iron. Here is a steel rail which has stood the wear of many millions of tons of traffic, and one at Chalk Farm is now wearing out the twenty-fifth face of iron rails adjoining it. In other words, twenty-four faces of double-headed rails have been completely worn out in four years under the traffic which has not yet worn out a steel rail at the same place. But this astonishing hardness is not purchased at the expense of toughness. Both of the great firms of steel rail-makers in Sheffield tested for us, on Saturday and Monday last, rails of like section, with three blows of a ram weighing one ton, and falling upon the head of the rail, supported upon bearings three feet apart in the clear, the ram striking in the middle. The first blow was given with a fall of twenty feet, bending the rail four or five inches. It was turned and took another blow, with the same fall, which straightened it horizontally, although it had a twist sideways. A third blow was then given with a fall thirty feet, which only bent the rail out of shape as if it had been of copper.

From every charge or "blow" a spoonful of steel is taken for testing the proportion of carbon. A complete chemical analysis is out of the question, and a standard piece of steel of which the proportion of carbon has once been accurately determined may, if it is not too large, be worth many times its weight in gold. From any standard test piece of steel, however, an approximate test may be established for all steels. A few grains are drilled out into chips and accurately weighed, and then dissolved in nitric acid of a specific gravity of 1.2 (pure nitric acid has a gravity of 1.522), and the color of the solution will be more or less brown according to the proportion of carbon contained. With a given weight of nitric acid, every proportion of carbon gives a different shade of brown, and so great is the range of color that the proportion may be ascertained with almost complete accuracy to the one-hundredth of one per cent., or to the ten-thousandth part of the total weight of the steel. Thus, if the standard steel be known to have 0.75 per cent. of carbon, and if an equal weight of the steel to be compared with it gives the same color of solution when dissolved in one-half the same weight of acid, the proportion of carbon is 0.375 per cent. After the complete solution is once made, water may be added to bring the solution to the standard color, and it is astonishing how nicely even the unpractised eye can judge of the difference of color between two test phials when placed side by side, and

held to the light with a piece of thin white paper behind them. A solution of steel changes its color in time, and therefore when a definite solution has ever been made, another solution of burnt sugar of the same color is prepared and hermetically sealed up in a phial, as this is used as the standard. The solution to be compared is brought to the same color by the addition of water, and the quantity added, as it rises in a graduated tube, indicates on a scale the proportion of carbon when the right color is reached. It is obvious that the standard solution, from whatever steel it is made, should be lighted in color, and therefore have less carbon than the solution to be tested, as it would be tedious to concentrate the latter, and thus deepen its brown color by evaporation. This lightness is had, when the standard steel of known composition has more carbon than the steel to be tried, by dissolving the former in twice or three times or other exact and ascertained proportion of acid more than the latter. In this way a steel known to contain 0.9 per cent. of carbon may represent, for the purposes of comparison, one containing only 0.45 or 0.3 per cent., and thus a steel with 0.54 per cent. may be compared with it by the dilution requisite to bring its own solution to the same shade of brown.*

It is the nature of the Bessemer process, and one of its greatest advantages and beauties, that its operations are always conducted and carried out on a very large scale. The melting pot, containing some fifty pounds of steel, has given place to the converter holding three or five tons and sometimes even ten tons of liquid metal; and a steel works of moderate size has one or two pairs of such vessels at its command. The Barrow steel works are the largest in Great Britain, the entire length of the sheds is 735 feet, the side walls carried up vertically twenty-eight feet. The pressure of the blast in the converters is twenty-one to twenty-two pounds per square inch, and the average duration of a charge is twenty-five minutes. There is occasionally a quantity of Swedish pig iron added to the charge, and the usual charge of spiegeleisen beside. Some of the converters are constructed for charges of seven tons, being twelve feet, ten inches diameter outside, and eleven feet clear diameter inside. Total height fifteen feet. This establishment

* Engineering, March 1st, 1867.

is furnished with the reversing roll train which we have described, and also Sieman's gas regenerator and is rapidly enlarging its dimensions.

Spiegeleisen for this Process.—One of the best sources for spiegeleisen and gray iron for the Bessemer process is the establishment of George Marienhütte, near Asna-brück, in Prussia. It consists of some coal mines and mines of brown hematite and spathic ore.

The furnaces produce only pig iron of the marks called "high quality," being those required for the production of best wrought iron and of steel. The marks are white iron for steel puddling, spiegeleisen and gray iron for the Bessemer process, and foundry iron. The present market for the produce of these works is the immediate neighborhood of its locality, viz., the steel works of Rhenish Prussia and of Saxony. Its principal applications are to the production of wire, boiler plates, puddled steel, and Bessemer steel. The foundry iron bears a high price on account of its great strength. Trials have been made at the Bessemer steel works, Sheffield, with both gray and spiegel iron from these works, and the results have been very satisfactory, in consequence of which a rapidly growing trade with this country is now being established.

Bessemer Steel in Sweden.—In Sweden we have the earliest successful attempts to make Bessemer steel, and indeed the first successful attempts in England were made with Swedish iron. The Fagersta works produce their own pig iron from a mixture principally magnetic ore, and hot blast and charcoal. The iron is gray and the mixture presents the following analysis:—

Carbonic acid	. 8.00	Manganese	. 3.35
Silica	. 17.35	Sesquioxide iron	32.15
Alumina	. 0.95	Peroxide	. 27.40
Lime	. 6.50	Phosphoric acid	0.03

The gray iron produced from this ore is applied to the Bessemer process without any addition of spiegel or other manganetic compound, the process being interrupted at the moment the desired steel has been made.

None but an experienced workman can tell by the flame when that time has arrived. Sometimes a little pig iron is added, but it is iron of the same character of the first charge. The analysis of this gray iron is as follows:—

Combined carbon	.	.	1.012	2.138
Graphitic carbon	.	.	3.527	2.773
Silicon	.	.	0.854	0.641
Manganese	.	.	1.919	2.926
Phosphorus	.	.	0.031	0.026
Sulphur	.	.	0.010	0.015

There is another mark of iron produced at Fagersta, used for the Bessemer process and also without any addition of spiegel, which is called two-third mottled as the proportion of gray to white is as two to one. The second column gives its composition.

Mr. Aspelin has analyzed the slag produced in the converter with gray iron after a complete charge making soft steel, and also the slag from the gray iron itself in the blast furnace. No. 3 is the blast furnace slag, No. 4 that of the converter.

	No. 3.	No. 4.
Silica	53.30	44.30
Alumina	3.00	10.86
Lime	21.10	0.65
Magnesia	13.95	0.15
Protoxide manganese . .	7.85	24.55
“ iron	0.90	19.45

The oxygen in the silica of the blast furnace slag is 27.56, that in the alumina 1.40, and that of the other bases 13.60. In the converter slag, the oxygen of the silica is 23.5, that of the alumina 5.10, and that of other bases 10.05. The magnesia in the converter slag may come from the clay lining. The steel is tested by Eggertz's carbon test, which we have described, p. 904.

The Styrian iron has long held a place second only to the Swedish for its purity and freedom from phosphates.*

Bessemer Process in Neuberg.—The Bessemer process having been introduced at Neuberg, with the intention

* Engineering, June 28, 1867.

of forming a model establishment, and a school for other iron works, the various operations connected with this process have been made the subject of very careful scientific investigation. The Neuberg works added to their exhibition at Paris, a list of analyses made with the metal and its corresponding slags or cinders, at various stages of the process, viz :—

	Pig iron.	First stage after disap- pearance of the sparks.	Second stage after the boil.	Third stage and of change.	Finished steel, with pig iron added instead of spiegel.
Graphitic carbon . . .	3.180				
Combined carbon . . .	0.750	2.465	0.949	0.087	0.234
Silicon	1.960	0.443	0.112	0.028	0.033
Phosphorus	0.040	0.040	0.045	0.045	0.044
Sulphur	0.018	trace	trace	trace	trace
Manganese	3.460	1.645	0.429	0.113	0.139
Copper	0.085	0.091	0.095	0.120	0.105
Iron :	90.507	95.316	98.370	99.607	99.445

The above analyses show, in the first instance, the excellent quality of the Neuberg iron for the Bessemer process. There are indeed very few even amongst the best Swedish marks of pig iron, the composition of which is so exactly suited for the requirements of this process, particularly with regard to the relative proportion of carbon and silicon. The absence, practically, of sulphur and phosphorus is of course one of the first conditions for success, and the analyses of the metal in various stages of conversion exactly correspond with the researches made on this point in England by Mr. Bessemer himself. They show the increase of the percentage of phosphorus in the refined product, as compared with the pig iron, an increase which is of course due only to the diminished quantity of the other impurities in the mixture with a constant quantity of phosphorus which remains present throughout all stages. It is interesting to find that copper follows the same law in the Bessemer process as phosphorus, as this had not been established by direct experiments in England, as far as we are informed. The fact of copper being in-

capable of removal by the Bessemer process makes the attention to its presence doubly necessary, and will explain several instances of failure in the Bessemer process, which could not be ascribed to any of the usual causes generally met with in English practice. The analyses of the corresponding slags taken from the same charge show the following contents:—

	Blast furnace cinders.	Slags taken from vessel at the first stage.	Slags from nearly second stage.	Slags from third stage.	Slags ultimately obtained.
Silica	40.95	46.78	51.75	46.75	47.25
Aluminum	8.70	4.65	2.98	2.80	3.45
Protoxide iron	0.60	6.78	5.50	16.86	15.43
Oxide of manganese	2.18	37.00	37.90	32.23	31.89
Lime	30.35	2.98	1.76	1.19	1.23
Magnesia	16.32	1.53	0.45	0.52	0.61
Potash	0.18	trace	trace	trace	trace
Soda	0.14				
Sulphur	0.34	0.04	trace	trace	trace
Phosphorus	0.01	0.03	0.02	0.01	0.01

There are some very striking points indicated by these analyses of slags. The sudden disappearance of lime and magnesia, for instance, compared with the much slower yet equally decisive decrease in the percentage of alumina in the slags. At first sight, it would appear that these substances must have been decomposed and carried away with the column of heated gases escaping from the vessel—an assumption which, although it cannot be said to be impossible, appears highly improbable at least. As it is not known, however, what proportional quantity of blast furnace slags enters the converter along with the pig iron, as compared with the new slags formed within the converter itself, another explanation can be found, by considering the decreasing percentage of the components of the blast furnace slags as simply due to the admixture of larger quantities of new slags formed principally by the oxidation of manganese, iron, and silicon. The quick disappearance of lime and magnesia, as compared with alumina, would still remain to be accounted for. In this respect it is possible that the blast furnace cinders, when tapped and run into the converter along

with the pig iron, do not form a homogeneous mass amongst themselves, that the cinders containing a predominance of lime and magnesia are less fluid than those formed by alumina and oxide of manganese, and that therefore the latter more fluid materials enter the converter in a larger proportion than the rest of the slags which are held back and remain in the runners. In this case the decrease of percentage of the bases forming the blast furnace slags would be simply due to the formation of new cinders containing different elements. With respect to the latter, the rapidity with which manganese, is attacked by the oxygen in preference to all other components of the mixture is clearly shown by the appearance of 37 per cent. of oxide of manganese in the slags after the first stage of the process. The combustion of silicon is only apparently small, comparing the 40.95 per cent. silica of the blast furnace slags with 46.78 per cent. in the converter ; but in reality allowance must be made for the silica left outside the converter, combined with lime and magnesia, and which must have been made up by the oxidation of fresh silicon contained in the iron before an increase in the percentage could take place. The slag analysis also shows that during the time of oxidation of the manganese no iron enters into the combustion, since the percentage of protoxide of iron in the slags remains constant till the close of the second stage, when no further oxidation of manganese is to be traced. We then find a small quantity of iron combining with the oxygen and entering into the slag. What influence the addition of fresh manganese in the spiegeleisen or pig iron added at the end of the process has upon the iron so oxidized, and whether any of this oxide is reduced at the expense of manganese, cannot be traced from the last two columns, since the effects of the admixture are obliterated by the addition of a fresh portion of blast furnace cinders carried into the vessel along with the pig iron added. We therefore find a decrease in the percentage of both elements, only the percentage of iron is reduced about four times more in proportion than the percentage of manganese, which certainly seems to indicate the reduction of a portion of iron

from the slag by the addition of metallic manganese, the latter entering at once into the slag. The Neuberg works also add the results of tests made with regard to the tensile strength of their material, without, however, stating on what scale these trials have been made, and by whom they were conducted. The results found are given in the following table:—

	No. of hardness.					
	Nos. 1 & 2.	No. 3.	No. 4.	No. 5.	No. 6.	No. 7.
Percentage of combined carbon.	1.12	0.88	0.62	0.38	0.15	0.05
	to 1.58	to 1.12	to 0.88	to 0.62	to 0.38	to 0.15
Tensile strength in tons per square inch.	not tested	63.13	57.65	40.17	34.43	28.69
		to 74.61	to 63.13	to 51.65	to 40.17	to 34.43

The steel No. 5, corresponds to the material used in England for railway tyres, crank-shafts, and the working parts of machinery; the No. 6 is used for boiler-plate, bridge-work, gun-barrels, &c., and the softest kind for sheet steel, wire and similar articles.*

Heaton's Cast-Steel Process.

Next to blowing air directly into and through melted iron, another mode of its conversion is that of placing within the iron substances capable of evolving oxygen. Mr. Bessemer, in one of his patents, No. 1981, A. D. 1856, proposed, indeed, to introduce, not merely air, but any gaseous matter containing, or “capable of evolving oxygen or hydrogen gas;” but there are some solid substances, such as nitrate of soda (NaONO^5) and saltpetre (KONO^5) which are ready vehicles of oxygen, and from which it may be evolved on heating to redness. This mode of producing oxygen is very destructive to the ordinary vessels employed in the process, and even affects platinum. Gold and silver cupels withstand the action, as would, of course, be expected.

* Engineering, May 3, 1867.

About 1866, Mr. John Heaton, then of Widnes, but now of the Langley Mill Steel and Iron Works, at Nottingham, patented a mode of treating melted iron with nitrate of soda or nitrate of potash (saltpetre) by placing either of these substances in pockets within the fire-clay lining of a revolving (or barrel churn) converter, where they might act upon the melted iron. Mr. Heaton had made experiments which indicated that about one cwt. of nitrate, worth perhaps 25s., sufficed to evolve enough oxygen for the conversion of one ton of iron. Mr. Heaton is now continuing his experiments in Nottingham.*

The London *Quarterly Journal of Science* for January of this year (1869) gives the process as follows: Cast-iron of any quality is first melted in a common iron-foundry cupola with coke fuel. A known quantity of the liquid iron, usually about a ton, is tapped out into an ordinary crane ladle, which is swung round to the side of the converter. This latter is a tall cylinder of boiler-plate, open at the bottom, between which and the floor a space is left. The converter has a fire-brick lining and terminates in a conical covering, out of which an iron funnel opens to the atmosphere. In the bottom of the converter a number of short cylindrical pots, lined with brick and fire-clay are adjusted. Into these pots a given weight of crude nitrate of soda of commerce is put. The surface of the powder is levelled and covered by a thick circular plate of cast iron. One of these pots thus prepared having been adjusted to the bottom of the cylinder, the converter is now ready for use. At one side of the cylinder is a hopper, covered by a loosely-hinged flap of boiler-plate. This plate is raised, and the ladle full of liquid cast iron is poured into the converter, and descends upon the top of the cold cast-iron plate. The plate does not float up nor become displaced, nor does any action become apparent for some minutes, while the plate is rapidly acquiring

* Engineering, March 29, 1867.

heat from the fluid iron above it, and the nitrate getting heated by contact with it.

Prof. Miller, of Cambridge, England, says, that after a few minutes the brownish-red vapors of the nitric oxide are seen, and then a lively deflagration ensues till all the carbon is burned out of the cast iron, after which a quiet follows, and the cast iron has become malleable, or steel according to the amount of carbon remaining.

Chrome Iron Steel.

Some experiments which have been made in our presence with this remarkable steel, lead us to speak of it as a new process and as distinct from all those previously mentioned for making steel.

About three years ago, or somewhat earlier, Mr. Baur undertook to experiment upon the effects of alloying malleable iron with aluminum. The results were excellent but not of an available nature. The lately imported mineral, cryolite, was then used with considerable success, but the corrosion of the crucibles rendered that method of obtaining aluminum, for the alloy, extremely expensive and uncertain. The next experiments were made with the chromate of iron, from Bare Hills, near Baltimore, and resulted in complete success. The malleable iron, of proper purity, is melted in crucibles capable of sustaining great heat. Some four to five per cent. of the chromate ore is then added, according to the desired temper, being scattered carefully, or simply dropped into the crucible when the latter is used, the contents are then properly mixed and cast. Great care, we understand, from the inventor, is taken to avoid all carbonized irons whatever, so that the steel is, as nearly as can be obtained, free from carbon.

This steel is certainly remarkable. We have seen it welded in a short bar upon itself—drawn out, tempered, and used as a cold chisel upon cast iron without the slightest difficulty and entirely without the use of any flux whatever. But one excellence consists in the fact that, when heated to a bright red heat such as would

utterly destroy the excellence of cemented steel, causing it to be "burned," this steel is not injured, but when thrust into water, again heated to a cherry-red and tempered in water, it assumes a uniform finely granulated appearance, and is immediately fitted for use. It has been lately tried in its welding powers, and makes a close weld upon cast iron. The only difficulty at present is its price. As the chromate of iron sells at present (July, 1869) for \$55 to \$60 per ton as an ore, and as the process is one wherein crucibles are largely used, that difficulty must continue for a while to exist. Roll trais may yet be erected and furnaces prepared with a view of reducing the price, which is an objection; but of its excellence there can be no doubt.

Nothing will more truly exhibit the value of this steel than the following results taken at West Point Foundry:—

Twelve specimens from three bars of $1\frac{3}{4}$ inch octagon tool steel, Nos. 1, 2, and 3. Two specimens were cut from each bar in the lathe, and two cut from each bar after heating it. The latter marked "H." The specimen is turned down in the middle to about one-half inch diameter, and this is the part broken in trials, being the centre of the bar, and consequently the most liable to imperfections. Results:—

		DENSITY.	TENSILE STRENGTH.
Bar No. 1	. . .	7.8464	181,830
" 1	. . .	7.8450	179,020
" 2	. . .	7.8339	176,920
" 2	. . .	7.8511	198,910
" 3	. . .	7.8161	173,770
" 3	. . .	7.8556	163,760
" 1 H	. . .	7.8373	183,620
" 1 H	. . .	7.8488	174,750
" 2 H	. . .	7.8386	168,530
" 2 H	. . .	7.8401	193,210
" 3 H	. . .	7.8229	174,540
" 3 H	. . .	7.8194	190,910

Highest strength of 12 specimens, 198,910 lbs.

Lowest " " " 163,760 "

Average of all the specimens, . 179,980 "

Or say, 180,000 lbs. per square inch.

Highest strength of steel given by Percy, is 132,909 lbs. per square inch.

The only manufactory of this steel is The American Tool Steel Co., Brooklyn, N. Y.

In this connection we give the following results, which, with what we have already given, cover all the steels hitherto spoken of:—

Tenacity of Wrought Iron and Steel.

Malleable iron.		Authority.
Wire, very strong (charcoal)	114,000.	Morin.
Wire, average	86,000.	Telford.
Wire, weak	71,000.	Morin.

Effects of Reheating and Rolling.

	Authority.
Puddled bar	43,904.
The same iron five times piled, reheated and rolled	61,824.
The same iron eleven times piled, reheated and rolled	43,904.

Steel and Steely Iron.

	Authority.
Cast steel bars rolled and forged { from 132,909. }	R. Napier & Sons.
“ “ “ “ { to 92,015. }	
“ “ “ “ . . . 130,000.	Rennie.
Blistered steel bars rolled and forged . . . 104,298.	Napier & Sons.
Shear steel bars rolled and forged . . . 118,468.	“
Bessemer steel bars rolled and forged . . . 111,460.	“
“ cast ingots . . . 63,024.	Wilmot.
“ hammered or rolled . . . 152,912.	“
Spring steel bars hammered or rolled . . . 72,529.	Napier & Sons.
Homogeneous metal bars rolled . . . 90,647.	“
“ “ “ “ . . . 93,000.	Fairbairn.
“ forged . . . 89,724.	Napier & Sons.
Puddled steel bars rolled and forged { from 71,484 }	“
“ “ “ “ { to 62,768. }	
“ “ “ “ . . . 90,000.	Fairbairn.
“ “ “ “ . . . 94,752.	Mallet.
Cast steel plates . . . { from 94,289 }	Napier & Sons.
“ “ “ “ { to 75,594. }	

In the above Mr. Kirkaldy experimented for R. Napier & Sons.

Musket's Steel.—Some pieces of this steel have found their way into our shops. It is a titanic iron and has the peculiarity of sufficient hardness after being heated red hot and forged, without any tempering. But it is not so tough as the last-mentioned steel, and upon a request on our part for a piece at one of the machine shops, a small hammer proved quite sufficiently powerful to

tap off a fragment. The steel is not white in fracture, but borders upon a tinge of straw-colored light brown. Mr. Baur, of the American Tool Steel Company's Works, Brooklyn, had a small ingot which bore very decidedly the above color and exhibited the comparative brittle characteristic just stated.

Remarks upon the Bessemer Metal.

When Mr. Bessemer began to manufacture wrought iron from cast, by blowing air into the molten metal, it was objected to the product that it had no fibre, as common puddled iron had, and that iron without fibre must necessarily be weak. It is now well known that homogeneous iron is much stronger than fibrous iron. But at the beginning of the manufacture, fibre was accounted as necessary in iron as in ropes or thread, a theory resulting merely from the accident of the production of fibre by the modes of manufacture then exclusively employed. In the case of iron produced by the common process, any bubble or vacuity in the metal becomes filled with slag, which hinders the sides from being effectually welded under the hammer. But in the Bessemer iron, as the slag is absent, the sides of the bubble cohere when the ingot is subjected to pressure while still hot. It is better to hammer the ingots while still hot, after having been poured, than to allow them to cool and to heat them afterwards. For in the one case the heart of the ingot is the hottest part, and in the other the coldest.

There is every probability that wrought iron will be soon almost wholly superseded in the arts by the mild steel of greater cohesive strength, such as the Bessemer process enables us to introduce. But the wrought iron made by the Bessemer process is stronger and better than other iron from its uniform and homogeneous character, and from the more complete extrusion of liquid impurities. Iron containing sulphur and phosphorus, which render it either hot-short or cold-short, is unsuited for the Bessemer process. The phosphorus sometimes comes into the iron from the improper selection of the

lime used as flux, which may contain coprolites, bones, or other phosphates, and in all cases it will be proper to avoid such sources of contamination. Numerous plans have been tried to discharge the phosphorus and sulphur contained in many kinds of iron in the Bessemer converter by blowing chlorine and other substances in with the air, so as to render those irons suitable for the process. But all these plans have been ineffectual, and the discovery of a mode of making these irons available for the Bessemer converter by simultaneous puddling and purification, remains a desideratum.*

Rolling Steel Rails.

In rolling steel rails in Messrs. Cammell & Co.'s Works, at Sheffield, the rolls, which are 21 inches and 22 inches in diameter, are run at about sixty revolutions per minute, and the hammered blooms are brought down to the finished section at one heat, the number of "passes" required to accomplish this of course varying according to the section of rail to be produced. In the case of the flat-footed rails, the number of passes required is fourteen, and the time occupied in rolling each rail is two and a half minutes. Of the fourteen sets of grooves through which the bloom is passed, the first and third are of a rectangular section, whilst the second, fourth, and fifth, through which the bloom is passed on its side, commence the formation of the bottom flange by compressing the upper part of the rail. Through the sixth pair of grooves the rail is passed with its bottom flange uppermost, and during its passage that flange is extended laterally, and a depression formed along its centre. Through the seventh and all the remaining pairs of grooves, except the ninth, the rail is passed on its side, its section being further developed at each pass until the rail is completed. Through the ninth pair of grooves the rail is passed, with its bottom flange uppermost, this pass completing the extension of the lower flange, and

* Engineering, March 15th, 1867.

removing the hollow formed in it by the sixth pair of grooves. After rolling, the rails, whilst still hot, are straightened by wooden mallets, and are then cut to length by a pair of circular saws. The two ends of the double-headed rails are cut simultaneously, but those of the flat-footed rails are under-cut one-eighth of an inch, so that the heads meet closely when the rails are laid, and each end has consequently to be cut separately.*

In the United States, steel rails are already largely introduced. They are upon the tracks of the Hudson River Railroad, Erie Railroad, Camden and Amboy Railroad, a few miles at Mauch Chunk and at Easton on the Lehigh Valley Railroad, the Pennsylvania Central, and on portions of other roads. The hardest, most homogeneous, and the best rail of those which we have noticed particularly, are upon the Lehigh and Susquehanna, running up the Lehigh from Easton, Pa., to Wilkesbarre, and beyond to Scranton. We have examined with particular care some parts of this road-rail compared with rails upon other tracks, and find that while upon some of the latter rails there have been found evidences of unequal carbonization, there appears a remarkable homogeneity in those laid upon the Lehigh and Susquehanna track. The evidences of deficiency are slight concavities or depressions of greater or shorter length immediately upon the surface of the head. Sometimes, when walking upon the road, these concavities may be very easily detected after a rain, when the examination is aided by the change of the angles of reflection. At other places the evidence is so plain that it may be very readily seen and tried at the immediate spot. We have seen no places greater in length than from two to six inches, and in some cases not more than one inch. The large coal transportation upon this railroad will make the trial of these rails more satisfactory than upon mere ordinary freight and passenger roads. At present the unevenness is not so apparent upon this road as upon some others, perhaps owing to the fact that the road has not been in use for a sufficiently long period,

* Engineering, March 1st, 1867.

but the transportation has already arisen to an exceeding amount, and the engines used are of very great tonnage, and the trial will eventually be a sufficient one.

Steel Capped Rails.—There has been no long-continued trial on any roads of these rails so far as we know, but preparations are being made on such a scale as to put them soon to the test. In these rails the body, the base, and stem, or shank, are of iron, and the cap piece only of steel.

Messrs. John Brown & Co., of Sheffield, are now rolling rails from the crop ends of Bessemer steel, and their managers inform the editor of *Engineering* that these rails weld quite soundly, and we have heard that steel-headed rails have been successfully made from these crop ends. In Europe such rails stand most thorough tests without separating.

W. M. Lyon, Esq., of the Sligo Iron Works, Pittsburg, Pa., recently subjected a steel-headed rail, made at the Wyandotte Rolling Mills, under the patent of S. L. Potter, to some rather remarkable tests. The rail was cut five feet long, and a weight of 1600 lbs. was allowed to fall upon it as follows: For the first blow, the weight was raised five feet; the second, ten feet. The rail was then turned over, and received the third blow with a fall of fifteen feet, and the fourth blow with a fall of twenty feet, bent the rail almost double. The rail was then taken to the steam hammer, whose weight was 8800 lbs. and received ten or twelve blows. When the bar was nearly straightened out, it broke, but the iron and steel remained perfectly welded together. One of these piece was then subjected to 100 blows from the 8800 lbs. hammer on the head of the rail as follows: fifty blows at two feet fall, and fifty at three feet fall. This crushed the rail without breaking the weld of the iron and steel. Tests of iron rail of other make were made at the same time, but the results were so unsatisfactory, that it is not necessary to notice them.*

Perhaps the following from the *American Rail Way*

* *Engineering*, April 19, 1867.

Times, of September 8, 1868, may present the actual practical progress in this direction as well as anything which may be written in so brief an article.

Mr. Peter Ashcroft, the engineer of the South Eastern Railway of England, claims great success for an invention of his in which he uses a small quantity of steel in the centre of the rail for the tread to run upon. He introduces between a pair of iron plates a steel rail, which fits in between the iron plates, the steel being tightly secured by screwing the iron plates up. The trains work only upon the steel, and when it is necessary to renew it, it is done by simply unscrewing the iron plates, taking the old steel rail out, and putting a new one in. Although it is claimed that this rail is working extremely well on the Charing-cross line, yet it is open to the objection that practice found the compound continuous iron rail to have: that the screws worked loose very easily and required very close attention to keep them in place, the same trouble that is found in the iron fish plates. A device may frequently work well in a limited way, when nursed and cared for by friendly hands, but which left to the rough every day practice common in railway operation, will fail; and this must be taken into account when we read of the success of many pet devices of inventors. While we confess we have some fears regarding the continued success of any compound steel and iron rail, we by no means discourage attempts to make these efforts certainties; and, it is for this reason that we always appeal to railway managers to give all practicable aid in the trials sought by inventors. Another device called the Duplex Steel and Iron Rail invented by Mr. J. L. Booth, of Rochester, N.Y., has been on trial on the New York Central and Lake Shore Roads for the past eighteen months, and as claimed with successful results. A Rochester paper thus describes the device: "Mr. Booth's rail is nearly in the form of a common T rail. The bottom, upright standard and a small head is made of iron; over this head is laid a cap of, or tread-piece of, steel, which forms the face of the rail, and is held in its place by clinching the head under on either side. These steel caps are rolled into place when the iron rail is cold, and are as firm as though the rail was one solid piece instead of two. If the caps are laid loosely upon the rail, experiment has demonstrated that the tread of the car wheels will in a short time make them tight. The bars are put into acid and the scale removed before they are put together. The ends are then ground and made true, thus producing a finished rail." It is stated that after eighteen months' wear in the Central track, in an exposed condition, these rails are now apparently as per-

fect as when first laid, while the iron rails laid alongside of them have been four times renewed. Mr. Booth is now making a quantity of these rails to fill a contract for the Central Company, the managers seeming to be satisfied with its success. These rails cost about fifty per cent. more than a first class iron rail, showing quite a saving in first cost over those of solid steel. The question of long continuous wear is still to be settled, however, in this as in all other compound rails; and to the end that all American devices at least, of compound steel and iron rails may have a fair comparative test of wearing qualities in the track, we suggest that a limited quantity of each of these rails be furnished to some company having a large and heavy traffic, and that these rails be laid where they will be equally exposed, and accurate accounts kept of the results by some careful person. As we have before said, all the devices are claimed to be successes, but as a matter of fact, it is well known that steel capped rails have failed, that the caps have peeled off, and that they have shown other defects when exposed to the hard test of driving wheels carrying a weight of from five to seven tons each, and going at high speed.

Steel capped rails have been made for considerable time and, apparently, with success by Waterman & Beaver, at Danville, Pa., and, although we have seen no trials of the rail, we have reason to credit the statement that "the rails from this company have been laid where there is almost constant 'shunting' and passing of trains, and where iron rails of ordinary quality last but about six months, the steel heads have been on the track eleven months, and as yet show no signs of giving out."

Weldless Steel Tyres.

Solid rolled tyres are becoming more and more generally applied. This is one of the many great results due to the introduction of the Bessemer process, which brought steel tyres into competition with iron, almost at an equality of price. Weldless tyres have been for some years made from cast steel, and there are still many steel-makers producing and selling crucible steel tyres. The process consists in hammering a large ingot into a cylindrical form, from which a number of short, disk-shaped pieces are cut off under the steel hammer.

Each of these disks is reheated and punched. A flat steel ring being thus obtained, the next operation is to widen the ring out under a steel hammer upon an anvil, with a projecting nose or beak, which gives to the ring a conical section suitable to being afterwards transformed, by rolling, into the flanged conical shape of the finished tyre. With smaller tyres Mr. Allen does not go through the expensive process of punching from the solid, but casts the ingots in the shape of two or three superposed conical rings. The construction of the ingot moulds for that purpose is very ingenious, and has been arrived at by a great number of experiments, surmounting gradually the numerous difficulties and obstacles which presented themselves. The conical rings, when cast in this manner, only require to be hammered once, and can at the second heat be finished in the rolling mill.

Mr. Rowan, in Glasgow, employs a double process of rolling in two mills, the first acting as a "breaking-down" mill and the second mill finishing the tyre found the ring produced from the first. This saves a great part of the hammering process, for which it substitutes the action of the breaking-down mill. With the aid of a double rolling process, tyres can be entirely finished from cast rings without hammering, and it is only a question of opinion as to the quality of material produced which leads to the application of either hammers or rolls.

The makers of pot steel tyres, as a rule, try to balance the greater prime cost of their material by casting it into such a form as to allow of its being finished with little additional labor. The method of casting is kept strictly secret both at Bochum and at the Sheffield Works; but its main principle is said to consist in casting into highly heated moulds, which are allowed to cool down very gradually, so as to temper and anneal the metal during the process of setting. The method by which Krupp's tyres are made is called in Germany "a public secret;" that is, it is known to everybody, yet not acknowledged by Mr. Krupp, or his authorized representatives. It is

not likely to differ from Mr. Bessemer's mode of production, except in trifling details.

Railway tyres are now considered the most profitable article of manufacture in the Bessemer steel trade; they pay a royalty of three pounds per ton to Mr. Bessemer, and with the more economical modes of manufacture now in practice it is not difficult to show that their present market price of twenty-eight pounds per ton will come down, and be reduced considerably at no very remote date.*

Trial of Rails.

The engineer of the permanent way of the Western Railway of France, sent the editor of *Engineering*,† a copy of a template showing the exact wear of some cast steel rails put down on the Anteuil branch of that line in October, 1860, being a wear of six years and four months. These rails are double headed, and are made to be turned, and measure from cap, or top of head, to cap (the shank being the connection between two uniformed caps), 5.1 inch, provided the copy of template in the above Journal be given in the exact size of template. The greatest wear in that time was 0.05 or $\frac{1}{20}$ of an inch, and is represented by an abrasion feathering to nothing before it touches the outside of the cap of the rail, and gradually increases till the inside upper edge is touched where it is greatest. This was due to the fact that the rail was upon a curve of twelve chains radius, and this was the outside rail. There are from forty-five to fifty passenger trains passing over this road daily, the lines worked by thirty ton engines, and the rails being greatly subjected to the wear of brakes. These rails are made of "pot" steel and not of Bessemer steel, but it is supposed that steel for this purpose could be made by the Bessemer process equally hard and tougher, the advantage of much less cost being had at the same time.

In the trials of these rails the sample is laid upon

* *Engineering*, Jan. 18, 1867.

† Feb. 22, 1867.

supports three feet apart in the clear, and struck at the middle of the span by a weight of one ton, having a striking edge at the bottom so formed as to give the blow at one point only in the length of the rail. This weight or ram is raised between guide-posts, and falls freely throughout its range. At a trial of this kind at the works of Messrs. John Brown & Co., and Messrs. Charles Cammell & Co., Sheffield, two sections were taken, one double-headed rail weighing sixty-eight pounds to the yard, of which the above firms are making for the Great Indian Peninsular Railway, each 11,000 tons, a sample from each firm was tested with about the same results. The first blow was given with a clear fall of twenty feet, and the rail was merely bent about five inches in the length of about four feet. No sign of cracking was exhibited. The rail was turned and struck with the same blow as before, and the same height less the curve of the rail, and this blow straightened the rail with a twist sideways. Another blow was given of clear thirty feet, which bent the rail more than before, but no signs of cracking appeared, and very slight indentation, showing great hardness and toughness combined.

Analysis of Steel.

The following is perhaps the most complete method of procedure in the analysis of steel. (Landrin.)

Pulverize about 150 grammes of steel in a steel pestle mortar; sieve; reduce coarse particles again; separate into three portions—No. 1 for carbon, No. 2 for sulphur and phosphorus, No. 3 for constituent principles, excepting combined carbon.

No. 1. *Carbon*.—Grind quartz sand with CuO , destroy organic matter by heating red (low); 30 to 40 grammes of this is mixed with equal quantity of steel and triturate in agate mortar; mix with six or eight times its weight of powdered chromate of lead. Introduce into a combustion tube, to be used with the ordinary precautions, putting into the end a few grammes of dry chlorate potash. Proceed as usual by heat. Pass CO_2

through chloride of calcium, absorb, weigh in a solution of caustic potash of specific gravity 1.28.

Nitrogen.—Mix some of assay with pure caustic soda, absorb the products of combustion in dilute hydrochloric acid in a vessel fitted for the reception; estimate in the usual way the chloride of ammonium formed.

No. 2. *Sulphur and Phosphorus: Sulphur*.—Treat with fuming NO_5 at moderate heat. Nitrous vapors escape without HS. Evaporate to dryness; treat with very dilute hydrochloric acid. Test with chloride barium in usual way. Filter after leaving vessel in a moderately warm place to settle perfectly. Precipitate excess of barium by SO_3 ; filter.

Phosphorus.—Add sufficient quantity tartrate of ammonia to prevent precipitation of iron and add ammonia in great excess. Pass HS through several hours. Let the liquid stand several hours in a warm place till it requires a yellow color. Filter rapidly, washing with NH_4S . Dry and expel ammonia by heat. The residue is composed of PO_5 with some CaO Al_2O_3 and alkalies with some iron. Melt all in platinum crucible with mixture of NaO , CO_2 and KO CO_2 . The melted mass is dissolved in HCl and PO_5 estimated by sulphate of soda. [This method of adding to the liquor previously supersaturated with ammonia—a solution of sulphate of magnesia is not accurate, and the liquor must be tested with molybdate of ammonia v. Rose.] *Sulphur* may be determined also by dissolving the pulverized steel in dilute HCl and passing H through the solution. The gas is received into an acid solution of acetate of lead, and the sulphide determined for the S which was in the steel. This analysis requires extreme slowness—the dissolving of steel requires not less than eight or nine days; pig iron ten to fifteen, and wrought iron four.

No. 3. Graphitic C. Si O_3 Ca O , &c., dissolve the same amount of steel in a long-necked matrass by gentle heat in dilute HCl —requires few hours, leaving dark, or black flakes floating. Collect the latter, wash, dry at 212 Fahr., This denotes the graphitic C with some Fe O Si O_3 and Ca O . Fuse the whole with nitrate of potash, mixed

with twice its weight of pure NaO Co_2 . Determine SiO_3 and CaO in the usual way. The difference is graphitic C. Proof: Dissolve an equal original portion of steel in dilute HCl . Collect flakes; dry upon an asbestos filter; mix with chromate of lead and CaO and proceed as previously directed. If right, the two analyses will exactly agree. Subtract graphitic carbon from carbon of original determination, and by difference we get combined carbon. The liquid filter from the flakes must be evaporated to dryness—treat again with dilute HCl —and the minute part of SiO_3 remains; add this to the SiO_3 from the flakes. If HS makes a precipitate, test what metals are thereby indicated; if nothing but white precipitate, then collect; peroxidize by NO_5 and boil; add ammonia, and lest all Fe_2O_3 is not precipitated add natural benzoate of ammonia, or, better, as producing less bulky precipitate, succinate of ammonia perfectly neutral. This gives the weight of metal (Fe .)

Traces of chromium or alumina: Dissolve the peroxide last obtained in HCl precipitated by excess of caustic potash which will dissolve those foreign substances which are generally in small quantities. If an excess of ammonia was not used previously to the use of benzoate of ammonia, the precipitated iron will not contain a trace of manganese.

Manganese.—The solution and washings must be evaporated to dryness; expel ammonia, then sulphide of ammonia. Collect MnS upon a filter after it has stood awhile and being slightly heated. Transform into MnSO_3 , or redissolve with HCl ; precipitate as carbonate. Calcine and weigh as red oxide.

Calcium.—Expel NH_4S by boiling, and then add oxalate ammonia. Calcine and weigh and the resultant CaO CO_2 indicates lime or calcium.

Magnesium.—May be traced by testing the filtrate with phosphate of soda.

Alkalies.—Evaporate solution to dryness, calcine and weigh as chlorides; then dissolve in a small quantity of water and separate the KO by a few drops of bichloride

of platinum and weigh chloride of sodium by difference.

(For some new methods see *Chemical News* (*American Reprint*, Oct. and Nov. 1867, and April and May, 1868.)

A method of determining the carbon in steel is one used very successfully in some places, by comparison of the shades of yellowish-brown resulting from dissolving the steel in muriatic acid and comparing the solution-shades with the shades of solutions of steels whose carbon has been already determined. These latter solutions, after determination, are hermetically sealed and serve as standard colors. See more fully under Bessemer Steel.

APPENDIX.

APPENDIX A. PAGE 40.

THE knowledge of certain minerals is important to the metallurgist. The following is a list of those minerals in the order of their importance, together with their metallurgical significance:—

Calcite is the generic term for all carbonates of lime, but when absolutely pure it contains, in 100 lbs., 44 lbs. carbonic acid gas and 56 parts lime and no water. But it is rarely found so pure, and the variations from purity are extremely important in the manufacture of iron. The color may vary with many shades of yellow and red due to iron, or pink due to manganese, or blue and green due to copper and chromium, or black and gray due to organic matter, or various mixed shades due to mingled elements; but the chief practical difficulties arise from mixtures of magnesia and quartz and alumina, as follows:—

1. *Dolomite*.—This is a magnesian-calcite and is made a distinct mineral species, but it is a mixture of carbonate of lime with carbonate of magnesia in greatly varying proportions, from 10 per cent. to as high as 67 per cent. of carbonate of magnesia. Veins sometimes occur in limestone rock which contain a high amount of magnesia, whereas the surrounding rock contains none worth noticing. It is of great importance to distinguish between these varieties of dolomite as greatly influencing the operations of the furnace. Illustrations of this importance we have given in another part of this work.

2. *Hydraulic Limestone*.—This is a calcite with large admixture of the principal ingredient of clay. Common clay contains quartz and alumina, colored yellow, or red by the presence of iron, or otherwise by other elements, as we have said under calcite. It is very important that these variations in the quantity of alumina and quartz in the limestone be known where they exceed two or three per cent. each. Beside the above, accidental elements appear, especially in the crystalline limestones, as small portions of

3. *Apatite*.—This is the name of lime when combined with

phosphoric acid, forming phosphate of lime. It occurs generally in small grains or particles which are not hard enough to scratch glass, are greenish or bluish-green, sometimes violet green, and especially in the magnetic ore, or granitic regions, and these particles occur frequently in some magnetic ores themselves.

Tests.—The readiest test for calcites is muriatic or nitric acid in a little bottle with a glass stopper. Sometimes the stoppers are extended to a point and can be used conveniently to draw out a drop of the muriatic or nitric acid. The use of a small half-inch focus magnifying lens will enable the analyst to detect the quantity of effervescence more readily in some specimens. If the specimen effervesces readily and largely, the signs are that the limestone is practically free from magnesia, alumina, and quartz, especially if a small particle broken off dissolves *entirely* in a drop of the acid, leaving nothing behind which can be seen by the *magnifying glass*. Dolomites and hydraulic limestones will effervesce less and less in proportion to the increasing amount of impurities they possess, and thus may certainly be detected by a little experience and afterward submitted to the various tests given in this work. The test for apatite may be found as above given, strictly distinguishing quartz grains which are frequently colored, but may always be detected by their hardness, as they will scratch ordinary white glass—apatite will seldom, if ever, be made to scratch glass so as to leave a line in the glass, if the glass is hard glass, but even in extreme cases the scratch is so uncertain as to cause no difficulty after a little practice. Breathing rapidly and fully upon a mineral or ore, and instantly catching the scent of the spot thus breathed upon, will, in many cases, reveal the presence of alumina by the degree of its slaty smell, and thus, in some, indicate the presence or absence of magnesia or alumina. Magnesian limes (dolomites), which will not show effervescence even under the magnifying glass, will, when powdered, dissolve, especially when warmed. A little practice will make such examinations very fine approximations and extremely convenient and useful when choosing limestones at the quarry and away from the laboratory.

Quartz is the mineral name of all kinds of flint, whether crystallized or massive, colored or limpid, translucent or transparent. Its base is *silex*; when pure it is simply the oxide of silicon. If much of it occurs in ores or limestones, it will materially affect the slags, and must be allowed for in the charges, as we have indicated under that head. Quartz sometimes resembles calcite, but as it is hard enough to scratch glass, and

calcite never is so hard, and as it will not effervesce nor dissolve in acids, it is easily distinguished.

Hornblende is the name formerly given, and now largely used, to indicate a rock which is very tough—not so hard as quartz, as it barely scratches glass—of a very dark-green or black appearance, and the freshly-broken pieces reflecting light with an almost imperceptible and finely-glittering or tremulous light. This mineral is found frequently in the magnetic ore, and sometimes in the red hematite, localities, but it is in the magnetic ores that its occurrence is important, as it frequently deceives even some of those who suppose that they are good judges of ore, and we have had repeated occasions to know that ores with a hornblende gangue sell better than ores of a better quality and higher per cent. without that gangue. Hornblende consists of silex chiefly, and much magnesia, lime, and alumina, with from 10 to 20 per cent. oxide of iron, but in very infusible combination. Some specimens vary in color and have very little protoxide of iron and more magnesia and lime; then it is white and may be called tremolite; with a little more iron it becomes light green, and is called actinolite. The name hornblende has been changed into amphibole in Dana's last edition, perhaps with no very sufficient reason, as hornblende (signifying *tough*) was in general use.

Pyroxene is a rock extremely similar to hornblende, but lime is a prominent ingredient in *all* the varieties of this species, whereas it is lacking in some of the varieties of hornblende.

Feldspar is a mineral frequently occurring with magnetic ores as a gangue. It is evidently not so hard as quartz, and yet harder than the last two. It may be distinguished from calcite in that it will not effervesce nor dissolve readily even when powdered and warmed. It is usually cream-colored, but frequently darker, with a dull, glassy reflection, from freshly-broken surfaces.

Kaolin is decomposed feldspar and frequently appears in white streaks in the brown hematite beds. It may be known by the greasy feeling following upon taking a little between the fore-finger and thumb and rubbing them for a few seconds together. The kaolin may be colored yellow or even bluish-black.

These are the most important mineral species to which the attention of the metallurgist need be turned at present.

APPENDIX. PAGE 84.

This is, without doubt, too high. The best English hammered iron in bars is taken at 25 tons per square inch (Fair-

bairn, 3d ed., Edinburgh, 1869, p. 330) which at 2240 lbs. to the ton would be but 56,000 lbs. A very excellent quality of iron made at the Catasauqua, Pa., Manufacturing Company, gave us, when tested at Reading, Pa., 58,000 lbs.; and another which was extremely well puddled and reheated (welded) 63,000 lbs. Very few puddled iron bars are equal to these. Instead of 71,000 then we may put 56,000 for the lowest tensile strength of a very good commercial iron.

For tensile strength of steel see at the end of Chrome Steel, Part IV.

The following is the strength of cast iron, extracted and condensed from the experiments of Fairbairn and Hodgkinson. All the coefficients are in pounds to the square inch:—

Kinds of Iron.	Direct tenacity.	Resistance to direct crushing.	Modulus of rupture of square bars.	Modulus of elasticity.
No. 1. Cold blast . . . from {	12,694	56,455	36,693	14,000,000
to {	17,466	80,561	39,771	15,380,000
" 1. Hot " . . . {	13,434	72,193	29,889	11,539,000
{	16,125	88,741	35,316	15,510,000
" 2. Cold " . . . {	13,348	68,532	33,453	12,586,000
{	18,855	102,408	39,609	17,036,000
" 2. Hot " . . . {	13,505	82,734	28,917	12,259,000
{	17,807	102,030	38,394	16,301,000
" 3. Cold " . . . {	14,200	76,900	35,881	14,281,000
{	15,508	115,400	47,061	22,908,000
" 3. Hot " . . . {	15,278	101,831	35,640	15,852,000
{	23,468	104,881	43,497	22,733,000
" 4 Smelted by coke without sulphur {	....	....	41,715	
Toughened cast iron . . from {	23,461	129,876		
to {	25,764	119,457		
No. 3. Hot blast after 1st melting	....	98,560	39,690	
" " " " " 12th "	....	163,744	56,060	
" " " " " 18th "	....	197,120	25,350	

APPENDIX A. PAGES 92 AND 177.

Almost any iron master may become expert, to a certain extent, in the use of the blowpipe for the determination of manganese, iron, silica, lime, and some few other elements. But general skill demands practice, a keen appreciation of shades of color and long experience. By R. F. we mean that part of the flame which is blue when blown with the introduction of the

point of the blowpipe into the flame. It is called the reducing flame, from the fact that substances which are oxides are deprived of their oxygen, or reduced by this flame; whereas the contrary effect takes place in the outer flame (or O. F.). Those who choose to practice may easily obtain a work on the use of the blowpipe. Such elements, however, as sulphur=S, phosphorus=P, arsenic=As, zinc=Zn, may be determined very easily by but little care if we except P. For detection of S, turning the blowpipe flame upon a small piece of the ore or suspected substance for a few seconds will give the smell of S. For As, the same act will produce the garlic smell of As. For Zn the flame upon charcoal will give a white lining upon the coal, which has a tinge of yellow while hot, and becomes white when cold; for P, if the base of the phosphoric acid gives no color to the flame, then the color will be bluish-green, if the mineral be moistened with sulph. acid before ignition. Bunsen's plan is to heat the substance in a wide closed glass tube, with three parts dried soda, and a small fragment of sodium; fusion makes a phosphide which after cooling yields phosphuretted hydrogen when moistened with water (Dana).

APPENDIX A. PAGE 128.

The best method of dissolving the ore or mineral for determining titanium and other similar metals in combination is that proposed by F. Wigglesworth Clarke, in Silliman's Journal, by means of fluoride of sodium, which latter salt is formed by boiling cryolite and caustic soda together in an iron vessel and purifying by crystallization.

The following is so much of the process as would be interesting to the iron analyst:—

Pulverize the mineral to 80 or finer to the inch; wash and determine water; one part assay is mixed with three parts F of S in suitable sized platinum crucible; on the *TOP* of this place twelve parts bisulphate KO, either in lumps or powder, heat *carefully* to tranquil fusion, keeping the crucible covered. Never mix the bisulphate with the F. of S. and the mineral. The mass obtained is dissolved either in water or H Cl. If volumetric assay is to be used, the basic undissolved salts may be made soluble in water by cooling the mass in the crucible, adding strong SO³ and fusing again; nearly always soluble in water after this. The latter is called second fusion.

RUTILE.—Rapidly and easily dissolves; residue is a yellow white mass; dissolves entirely in cold water, without second

fusion. From this solution all the titanic acid may be thrown down by boiling.

ILMENITE—like RUTILE.—Some basic salts remain soluble in HCl by fusion No. 2; all soluble in cold water, and titanic acid is precipitated by boiling.

CHROMIC IRON ORE.—Decomposed easily, in less than three minutes from the time it is heated with ordinary Bunsen gas-burner; mass light green; partly soluble in water alone, and entirely soluble in HCl. Fusion No. 2 makes larger proportion soluble in water, but always some basic salt remains soluble in HCl.

HEMATITE.—Hardest kind easily reduced; soluble in water partially, entirely in HCl. By fusion 2 all becomes soluble.

LIMONITE and MAGNETITE.—Like Hematite.

CHROMIUM IN CHROMITE.—After fusion, as directed, treat mass with HCl for ten minutes, then upon boiling with water all dissolves; neutralize the solution and add acetate of soda, and oxidize the chromium to chromic acid by a current of chlorine gas or by boiling with hypochloride of soda solution. The chromium may then be separated from other substances by Prof. Gibb's method (*Journ.* Jan. 1865). When chromite is fused as above, and saltpetre added to the mass, as soon as the fusion ensues the chromium is nearly all oxydized to ChO^3 . If the mass be boiled with solution of NaOCO^2 and the liquid filtered, a filtrate is obtained which contains nearly all the chromium or alkaline chromates free from iron or alumina, but the residue on filter paper contains traces of chromium.

Technical estimation of IRON in ORES, SLAGS and CINDERS.—After fusion, if Penny's process with bichromate potass is used, or the ordinary method by precipitation by ammonia, the mass may be treated with HCl and thus brought into solution. If by permanganate of potass, it must be fused again with SO^3 . The clear solution may be separated into three parts, under ordinary precautions, one for iron by volumetric assay or by precipitation, the other for titanium by boiling down, the third for lime, magnesia, alumina. Sulphur, phosphorus, and silica must be determined otherwise.

In all the above, cryolite (pure) may be used, but not when alumina is to be determined.

APPENDIX B. PAGE 36.

In addition, we may add that Prof. Rogers in his report gives analyses of magnetic ores, from other mines, as follows:—

	Perox. iron.	Protox. iron.	Silica.	Alu- mina.	Mag.	Lime.
Near Isabella Furnace, Chester Co.	..	76.86	..	..	..	..
Schmultz farm, Alsace, Berks Co.	57.10	24.50	12.10	4.15	.52	.60
$\frac{1}{2}$ mile E. of Reading, Penn's Mt.	36.50	16.25	24.17	6.20	7.10	5.67

	Potash.	Titanic (and other acids).	Water.	Metallic iron in 100 parts.	Description.
Near Isabella Furnace, Chester Co.	..	2.39	..	..	Black, crys- talline, specks of hornblende Cryst. with hornblende, feldspar, quartz, apatite.
Schmultz farm, Alsace, Berks Co.	..	.75	.28	58.95	
		Phos. & fluor.			
$\frac{1}{2}$ mile E. of Reading, Penn's Mt.	3.30	.81	..	37.00	

In Pennsylvania there are also other beds of magnetic ore, one south of Easton $2\frac{1}{4}$ miles, a few rods northwest of the old Philadelphia road, but it is abandoned (Rogers). Efforts are at present being made to open near the same locality. There is magnetic ore for miles along the top of the ridge, but it has not been removed in any large quantity. The mine, not far south of Durham Creek, about three miles southwest of Durham furnace, near Riegelsville, is a large mine, successfully worked at present, July, 1869, and supplying the neighboring furnace.

At the Mount Pleasant mines, on border of Colebrookdale and Hereford township, there was mined, formerly, a compact ore; also two miles northwest from Friedensburg, a mixed ore; near Princeton, on Rauzbaun's farm, said to be excellent magnetic (Rogers); also two miles east of Pricetown. Around Bethlehem, and for many miles westward and eastward, ore has been found and dug, but not extensively mined. The most interesting beds in the State are found at Cornwall mines and Lebanon County, not far off the line of the Reading and Harrisburg Railroad. This ore abounds with sulphuret of iron, and some specimens contain copper. We have seen an excellent magnetic ore taken from a mine not far from Allentown, between one and two miles from Millertown station, on the East Pennsylvania Railroad, called the Rock Ore mine.

APPENDIX C. PAGE 51.

Rogers gives as an analysis of one of these argillaceous ores the following: Specimen from Summit mine of Lehigh, Pa. perox. of iron 37.40; silica and insoluble matter 45.65; alumina 18.60; water 4.00; metallic iron 22.98. Remarks: slate blue, compact, nodular, conchoidal, rusty. Of another from Mount Eagle, Black Spring Gap, Dauphin County, the following is the analysis: Carbonate of iron 73.94; perox. of iron 10.36; carb. of Mn. 2.95; carb. of mag. 2.07; silica and insoluble matter 6.63; carbonaceous matter 1.54; water 1.99; metal. iron 42.22. Remarks: nearly black, slaty. The ingredients of these coal measure ores are carbonate of iron chiefly, next peroxide, with large amount of silica and insoluble matter, alumina, carbonates of lime, magnesia and manganese with carbonaceous matter and water. Their color generally blue, sometimes brownish and nearly black.

APPENDIX D. PAGE 56.

In Pennsylvania, also in North American mines, Pottsville, near Wilkesbarre, in the Lackawanna Valley, in Clearfield County, at Karthaus; Paint Creek, Cambria County; Bear Creek Hill, Blossburg, Tioga County; Blairsville and Lockport, Westmoreland County; Phipps' Furnace, Scrubgrass, Venango County; at Kutcher's, Clarion County; and at Buffalo Creek, Armstrong County. All these ores are blue, slate blue, or brownish-blue.

APPENDIX F. PAGES 129 AND 177.

According to experiments by Faraday and Stodart, steel and platinum will alloy in all proportions, and the platinum will fuse in contact with steel at a temperature which will not affect the steel at all.

The following method, which is the most complete, has been furnished us by Chas. P. Williams, A. M., late Professor in Polytechnic College, Philadelphia.

Two portions of about two grammes each are weighed.

Portion A. Dissolve in sulphuric acid in a quarter litre flask into which a current of carbonic acid gas is passing. After solution, which is aided by heat, the liquid is diluted with distilled water and brought up to the given standard (250 c. cs.)

and the amount of FeO determined in several separate parts by means of a solution of permanganate potassa of known strength.

Portion B is carefully dried in an air-bath at a temperature of about 220° Fah. till it ceases to lose weight. The loss, = *Hygroscopic Moisture*.

It is then ignited at a strong red heat in a current of dry carbonic acid. Loss in weight, = *Combined Water*. (Note I.)

The residue is now carefully mixed with about four times its weight of a mixture of carbonates of soda and potassa to which some little nitrate potassa is added (to oxidize the sulphur) and fused in a platinum crucible. The fused mass is extracted with water, = residue "a" and filtrate "a".

To filtrate "a" add hydrochloric acid and evaporate to dryness in a water bath; moisten with hydrochloric acid, add water and filter. The small amount of SiO_2 which is separated by this filtration is added to residue "a". The filtrate is measured and divided into two equal parts "b" and "c".

To "c" add $BaCl = BaOSO_3$ which is dried, burned and weighed and the amount of S calculated and multiplied by 2, for the amount of S in the ore.

To "b" add $NH_4Cl + NH_4 O + MgO SO_3$ = precipitate of $NH_4 O 2 MgO PO_5 + 14Aq$, which is ignited and weighed as $2MgO PO_5$ from which the amount of PO_5 is calculated and doubled for the whole PO_5 in the ore. (Note II.)

Residue "a" is dissolved in hydrochloric acid and evaporated to dryness in a water bath, treated with hydrochloric acid and water = residue $a^1 = SiO_2$.

Filtrate from a^1 (which contains $Fe_2 O_3$, $Al_2 O_3$, MnO CaO and MgO) is carefully measured and an aliquot part taken for the separation and estimation of the bases. This is done because the large amount taken and requisite for the estimation of the S and PO_5 would give, at this stage of the analysis, such large precipitates as to be difficult of washing, etc.

This portion is carefully neutralized by the carbonate soda and boiled with solution of acetate soda [See Fresenius' "Quantitative Chemical Analysis," page 195, fourth English edition] Precipitate = $Fe_2 O_3 + Al_2 O_3$. (Note III.)

This precipitate is dried, burned and weighed and the weight of the mixed oxides noted. It is fused with KO_2SO_3 HO dissolved in water, tartaric acid, and then ammonia and sulphide ammonium added. The iron is precipitated as FeS whilst the alumina remains in solution. The FeS is dissolved in HCl , peroxidized by nitric acid and precipitated by ammonia in the usual way and weighed as $Fe_2 O_3$. This weight deducted from the weight of the mixed oxides gives the $Al_2 O_3$.

To the filtrate from the $Fe_2 O_3 + Al_2 O_3$ a few drops of acetic

acid and then bromine are added; boiled till there is no longer an odor of bromine. Precipitate= MnO_2 which is ignited and weighed as Mn_3O_4 . (Note IV.)

Oxalate ammonia and ammonia are added to the filtrate. Precipitate= CaO which is strongly ignited and weighed as CaO . (Note V.)

A solution of phosphate soda added to the filtrate now precipitates the MAGNESIA as $2\text{MgO} \cdot \text{NH}_4 \text{O}^s \text{PO}_5 + \text{Aq}$, which is weighed as $2\text{Mg}_3\text{O}^b \text{PO}_5$. (Note VI.)

The various precautions to be observed in the different filtrations are fully described in Fresenius' or Rose's work on Quantitative Analysis, either of which can always be consulted with advantage, by the analyst. The only point of originality claimed beyond the detail of the arrangement is the use of bromine in the separation of manganese. It is much less troublesome and far more satisfactory than the employment of chlorine for the same purpose.

The author has followed, in the main, this method for upwards of eight years, both for the purposes of ordinary commercial analysis and for instruction of students. He has found it expeditious in its results and of easy comprehension by those who have not followed a full course of qualitative or quantitative analysis.

From the data accumulated by the analysis the following method of expressing the result is usually employed:—

Result of Analysis Sample Iron Ore Marked —.

	Per cent.
Moisture at 212° Fahr.
Combined Water
Peroxide Iron
Containing Metallic Iron
Protoxide Iron
Containing Metallic Iron
Bi Sulphide Iron
Containing Sulphur; Metallic Iron
Phosphoric Acid
Containing Phosphorus
Alumina
Protoxide Manganese
Lime
Magnesia
Silicic Acid
The total per cent. Metallic Iron =	—

Should CARBONIC ACID be one of the constituents of the ore it should be determined in a separate portion, weighed at the same time as A. and B., by means of the ordinary carbonic acid apparatus. ARSENIC, if present, will be found in the form of arsenic acid in the watery solution which contains the sulphuric

and phosphoric acids: To separate and estimate it, the half of the solution used for the phosphoric acid is first treated with sulphurous acid (to produce AsO_2 to AsO_3) and then a slow and long-continued current of sulphydric acid gas is passed through. The arsenic is precipitated as As_2S_3 which is separated by filtration. The filtrate is boiled to expel the sulphydric acid, and then treated as above described for phosphoric acid.

COPPER, occasionally present in small quantity in iron ores will be found in residue "a," and may be separated, after the removal of the SO_2 by filtration, by means of sulphydric acid. The filtered sulphide copper is mixed with sulphur, burned in a current of hydrogen gas, and weighed as Cu_2S . The filtrate is boiled to expel the sulphuretted hydrogen; peroxidized by means of nitric acid or chlorate of potassa, and the other bases separated as given in the method above.

These substances, copper and arsenic, are of more frequent occurrence, especially in limonite ores, than is usually supposed. They are only to be found by a critical and searching analysis, and are consequently frequently overlooked. A. Müller (*Annal. d. Chem. und Pharm.* 86, 127), found in an ore used at Carlshütte, weighable amounts of arsenic and vanadic acids, and potassa, and traces of chromium, copper, and molybdenum.

NOTES TO THE ABOVE METHOD.

I. If the ore contains organic matters the loss in weight will express the joint weight of the combined water and organic matter. A separate estimation of the water can be made, if considered necessary, by means of a chlor-calcium apparatus.

II. It is always safer to redissolve this precipitate in hydrochloric acid, and reprecipitate by the addition of ammonia. By this means the danger of weighing some of the carbonate of magnesia, which always separates as phosphate and consequently increasing the amount of PO_5 , is avoided.

III. All the iron is weighed here as sesquioxide. It is necessary to deduct the weight of iron existing as protoxide (obtained from portion A.), the remaining Fe is calculated to Fe_2O_3 , unless an appropriate amount of S has been obtained, when the Fe required by this to form FeS_2 should also be deducted.

IV. The MnO_2 requires strong ignition, which should be repeated till two successive weighings agree.

V. The conversion of oxalate lime into lime rather than into a carbonate is much less troublesome and more certain.

VI. It is not necessary to redissolve this precipitate as there can be, of course, no separation of excess of magnesia.

APPENDIX G. PAGE 249.

The oxide of copper process depends upon the power of this oxide to furnish oxygen which, combining with the carbon, forms carbonic acid gas. The latter passes through a solution of pure caustic potash, which, thus becoming carbonate of potash, furnishes the data for determining the carbon. The substance to be tested is placed, with precautions, in a tube with the oxide and heated. A most accurate method of procedure with the oxide may be seen in Prof. Johnson's report on coals.

APPENDIX H. PAGE 255.

Strip of silver foil with a small per cent. of copper alloy, may be used, the time and color deciding, with practice, the amount of sulphur. The nitro-prusside of potassium may be used with considerable success in the following manner: file, into powder, the suspected iron, cover it upon charcoal, with carbonate of soda mixed with a little starch, turn the blowpipe flame cautiously upon it till gathered into a mass by semi-fusion, then instantly drop the clean or white mass into a solution of the nitro-prusside of potassium in water in a watch crystal, and on the edge will appear a reddish-purple color or tinge according to the amount of sulphur. Only a fragment the size of a pin head should be dissolved in one drop of water, and a magnifying glass be used. Generally about one grain of filings is sufficient. Practice with this process makes very perfect.

PAGE 341.—These "costs" must be regulated by proximity to the sources of supply. Magnetic ore costs at the Lehigh from \$6 to \$11.50, according to the source of the ore, Morris County, N. J., or Champlain, N. Y. So with coal, if anthracite. On the Lehigh, iron costs, in some places, nearly one-third more than is indicated in the text, in ordinary furnaces. Since the above was written, Mr. Henderson has sent us the following estimates for June 16, 1869:—

2 tons hematite at \$6 per ton at furnace	. . .	\$12.00
$\frac{1}{2}$ ton magnetic at \$7 " "	. . .	3.50
1 " coal (they now use 2 tons)	. . .	3.75
Limestone	. . .	1.75
Labor and repairs	. . .	3.00
Freight to N. Y.	. . .	2.50
		<hr/>
		\$26.50

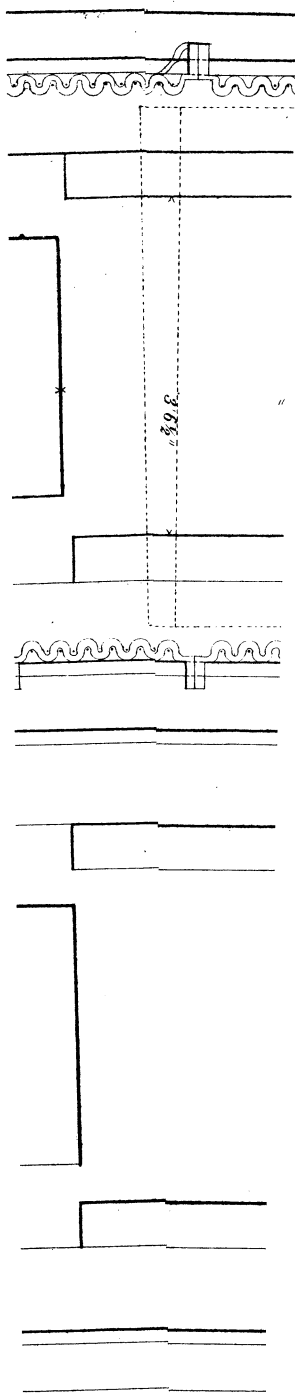
Can be done on the Hudson in large furnaces, at present rates, for the following cost:—

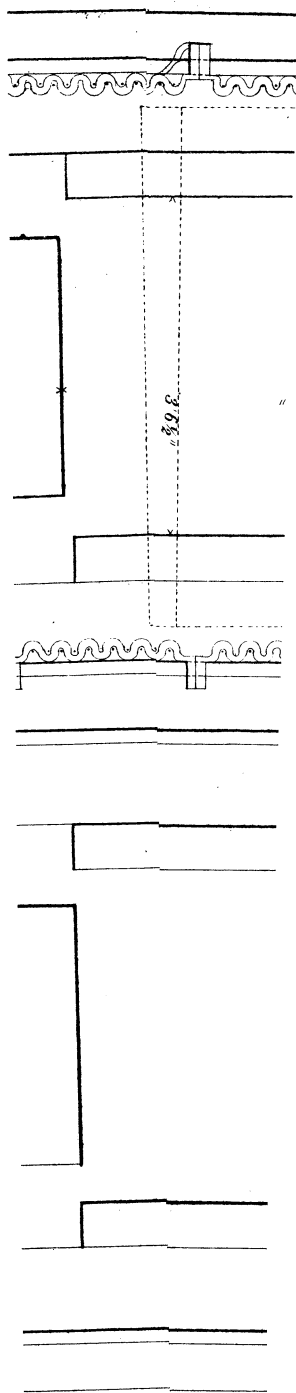
1 ton (50 per cent.) hematite	.	.	.	.	.	\$4.50
1 " (50 per cent.) magnetic	.	.	.	.	.	4.50
1 " coal [?]	.	.	.	.	.	4.50
Limestone	.	.	.	.	.	1.00
Labor and repairs	.	.	.	.	.	3.00
						<hr/>
						\$17.50

But we are well assured that the above estimates must be greatly modified by conditions not expressed by these figures which are merely theoretical, especially in coal and limestone: extremely few furnaces use half hematite to half magnetic even on or near the Hudson, and none that we are aware of on the Lehigh. Nevertheless under some circumstances the above costs will be approximations modified as we have said by skill and proximity to the sources of supply.

APPENDIX I. PAGE 286.

The firm name has become Shoenberger & Co. We have given the process in full and the result of new experiments and fuller trials under Malleable Iron.





INDEX.

"Let no book lack an Alphabetical Index."—S. A. ALLIBONE, LL. D.

"So essential did I consider an Index to be to every book, that I proposed to bring a Bill into Parliament to deprive an author who publishes a book without an Index, of the privilege of copyright, and, moreover, to subject him for his offence to a pecuniary penalty."—LORD CAMPBELL. "*Lives of the Chief Justices*," vol. iii., preface.

- Abel's analysis of steel, 900
- Aberdare iron works experiments, 106
- Absorption of gas by charcoal, 223
 - of water by charcoal, 223
- Abstraction of silicon from cast iron, &c., 122
- Accidents in furnaces, 398
- Accounts, keeping, 839
- Accumulation of coal in boshes, 378
- Acid, ferric, 24, 95
 - permanganic, 27
 - phosphoric, 23
 - silicic, 25
 - sulphuric, 23
 - from pyrites, 101
 - sulphurous, 23
- Acids, 21
- Acklam furnaces, 342
 - iron, analysis, 448
- Action of heat in iron, 84
 - of iron in phosphate of lime, 106
 - of ores in the furnace, 415
 - of phosphorus on iron containing carbon and sulphur, 121
 - of sea water on iron, 123
 - of sulphuric acid in cast irons, 123
 - of sulphur on iron containing carbon, 120
- Acre, wood to an, 182
- Acute angle, tuyeres, 590
- Adurn, 275
- Advantage of double puddling furnace, 682
 - of fermentation, 747
 - of finery, 749
 - of puddling, 695
 - of high furnaces, 337
- Advantages of chimneys open at side, 353
- Advantages—
 - of gas furnace, 855
 - of Johnson's furnace, 869
 - of Lurmann's improvement, 345
- Affinities, 728
- Affinity for carbon, 412, 421
 - of oxygen, 19
 - of silicon for iron, 498
 - of tin for iron, 127
- Africa, iron manufacture, 276
- Aich metal, 126
- Aim of the iron manufacturer, 390
- Air chamber for blast fan, 579
 - composition of, 18
 - dried peat, 185
 - engine hoist, 605
 - furnace, assaying in, 168
 - cast steel, 879
 - hammers, compressed, 806
 - heating stoves, 488
 - hoist, 602
 - introduced by blast, 368
 - moisture in, 632
 - shafts, 76
- Airdrie black band, 53
- Alabama, brown hematite, 46
- Alcohol added to green vitriol, 102
- Alden's blower, 562
- Alexander on fuel consumed, 425
- Alkalies, 926
 - dissolved by chlorides, 741
 - ferrites of, 90
 - proper, 427
 - tendency to dissolve metallic oxides, 428
 - to form cinder, 736
- Alkali in forge cinder, 732
 - in puddling, 748
 - in wood ashes, 180

Alkali—

to remove silex, 732

Alkaline cinder, 745.

earths, 426, 427

silicates with protosulphide of iron, 99

Allen's steel tyres, 922

Alloy of chromate of iron, 913

of copper and zinc, 126

of steel and platinum, 936

of titanium, 127

with aluminum, 129, 130, 913

antimony, 128

calcium, 133

chromium, 130

gold, 129

lead, 128

magnesium, 134

nickel, 128

palladium, 129

platinum, 129

potassium, 133

rhodium, 129

silver, 128

tungsten, 133

vanadium, 134

Alloys, chemical properties as, 89

of iron, 124

make iron fusible, 423

Alluvium, 63

Alumina, 26, 427

absorbs phosphorus, 428

from limestone, 149

in limestone, 147

in ore detected, 172

Aluminous ore, how detected, 139

Aluminum, 26

in wootz, 881

alloy, 129, 130

with malleable iron, 913

American Bessemer process, 868

black-band, 54

coal, 245

elliptical siphons hot blast, 510

processes, 280

substitute for the squeezer, 813

uses of steel, 887

Ammonia in iron, 82

in rust, 96

magnesian arseniate, 107

Amount of blast, 482

of carbon in iron, 115

of fuel for a charge, 388

Amphibole, 931

Analyses, comparative of iron, 691

of anthracite, 207

of ashes for bituminous coal, 189

of Bessemer steel of Neuberg, 908

of bog ores, 56

of cinder, 734

Analyses—

of coal ashes, 187

of fossil ores, 49

of furnace cinder, 431

of iron, 114

of Neuberg slags, 909

of ore, 866, 867

of ores, 935, 936

of puddled steel, 895

of scotch black bands, 53

of slags, 452, 453, 454

of wood ashes, 181

Analysis, expressing result of, 938

of a furnace deposit, 484

of an ore, 479

of Bessemer steel, 900, 906

of black band ore, 52

of bomb ore, 463

of Brighton ore, 434

of cinder of run-out fire, 748

of Cleveland slag, 449

of coal, 209

lessons from, 251

of coals, remarks on, 249

of coke, 448

of iron from Acklam, 448

of limestone, 148, 461

of marquette ores, 37

of nodular hematite, 463

of ore, 433, 434

necessary, 135

of ores, 279, 471, 472

chemical, 171

of peat, 226

ashes, 184

of relative value of fuel, 243

of slag, by Aspelin, 907

of Spiegeleisen, 119

of steel, 924

of titaniferous ores, 475

of wootz, 882

Analyzing limestone, 146

Ancient form of a heating oven, 829

Anhydrides, 29

Anhydrous, 29

oxide of iron, 90

sesquioxide, 31

sesquioxide of iron, 39

Annealed steel bar, 119

Anthracite coal, 186, 198, 204, 205

coal of Pennsylvania, composition

of, 207

furnaces, 310, 410

iron, 718

puddling furnace, 669, 670

value of, 244

Antimony alloy, 128

Antwerp, N. Y., mines, 42

Anvils, 760

Apatite, 929, 930

- Apparatus, hot blast, 489, 502
 Appendix, 929
 Application of blast, 367
 of fluxes, 371
 of fans, 565
 Arch, height of, 716
 Arches of furnace, 350
 Argil, 76
 Argillaceous carbonate of lime, 47
 iron ores, 50, 54
 ore, 936
 how detected, 139
 of the coal formation, 61
 ores, 26
 assay of, 141
 Armstrong's hydraulic hoists, 601
 Arseniate of sesquioxide of iron, 107
 Arsenic, 938
 detected in ore, 177
 extracted from iron, 107
 and iron, 107
 steel by, 109
 Arsenical iron taken for silver, 108
 Arsenides of iron, 107
 Arsenious acid in green vitriol, 102
 Arseniurets of iron, 258
 Artificial cement, 154
 fluxes, 713
 puzzolanas, 155
 refractory stones, 535
 sandstone, 536
 volcanoes, 97
 Asbestos, 486
 Ashcroft's steel rails, 920
 Ashes, 179
 of peat, 183
 wood, 718
 Asiatic method of making iron, 638
 Aspelin, analysis of slag, 907
 Assay by Mushet, 139
 classification of ores, 166
 dry, of ores, 155
 volumetric, 169
 wet, 169, 171
 with bichromate of potash, 169
 with permanganate of potash, 170
 Assayings, directions for, 168
 Assays, 140
 with charcoal, 156
 with fluxes, 160
 Atmospheres, vapor of water in, 18
 Augustin, cubes of iron, 83
 Austrian blowing engine, 576
 Austria, piling in, 839
 Average, 82
 yield of puddled bars, 839

 Bad iron, 143, 720, 731
 causes of, 497
 pig iron, 736

 Bagnold's account of making Damascus
 steel, 883
 Balling, 808
 water in a blast furnace, 632
 Balliot's mine, 45
 Baracaldo, proportion of, 280
 Bar iron, 727, 844, 847
 acquires crystalline form, 86
 of permanent fibre, 734
 steel, 873
 steel from, 873
 Barruel on electro-deposited iron, 82
 Barrow for coal, 384
 Barrow-in-Furness, 449
 Bars, saws for cutting, 837
 Baryta, ferrate of, 95
 with protosulphide of iron, 99
 Base, forge cinder as a, 734
 Basic chloride of lead as a flux, 742
 Bauerman on surface-hardening, 109
 on the Corinthian gas-puddling
 furnace, 859
 Bauerman's analysis of blackband, 53
 Baur on alloy with aluminum, 913
 Beds of iron ore, 31
 Bedson's continuous mill, 816
 Belgian coke furnaces, 629
 Bellows, gasometer, 557
 Indian, 881
 iron cylinder, 548
 Swedish, 544
 wooden cylinder, 544
 wooden, 543
 Bellside blackband, 53
 Benefit of raw coal, 254
 Benefits of clay in iron-working, 746
 Berthier on compounds of iron, 98
 on silicates with protosulphide of
 iron, 99
 on value of fuels, 244
 Berthier's table of charcoals, 222
 of refractory products, 541
 Berzelius, foreign matters in bar iron,
 723
 on phosphate of iron, 106
 Berzelius' plan for pure iron, 81
 Bessemer metal, remarks on, 916
 process, 868
 in Neuberg, 907
 steel, analysis, 900, 906
 in Sweden, 906
 Bessemer's process for steel, 898
 royalty, 923
 Best form for blast furnace, 315
 iron, 59
 Bichromate of potash, assay, 169
 Binder, end of key of, 352
 eye of, 352
 Binders of furnace, 352
 Bisulphide of iron, 100

- Bisulphide of iron—
 in the air, 103
 Bituminous coal, 186, 188
 charring, 227
 Black-band, 51
 ores, 50
 Black cinders, 398,
 crystallized carbon, 22
 Diamond Works' steel, 891
 iron sand, reduction of, 275
 oxide of manganese, 27
 Blacklead crucible, 158
 Blacksmiths, iron for, 706
 Blaseofen, 277, 628
 Blast, 367, 629
 consumption of, 628, 692
 engines in United States, 200
 furnace, 295
 at Hyanges, 310
 building, 347
 iron, puddling from, 689
 to remove impurities, 749
 furnaces, affected by rain, 632
 at Pennsylvania Iron Works,
 471
 best form, 315
 combustion in, 402
 difficulties in, 633
 disorders in, 383
 fluxes for, 144
 inspecting, 629
 management of, 373
 moisture in, 631
 theory of, 402
 titaniferous ores in, 474
 machines, 542, 547, 548, 555
 fan, 559
 remarks on, 597
 wooden, 547
 oven, Player's, 516
 pipes, 581
 law of, 594
 pressure of, 561, 566, 595
 quantity of, 566
 starting, 376
 stopping the, 610
 theory of hot, 494
 Blasting, 66
 tools, 66
 Blasts, calculations upon sizes, 620
 pressure and amount, 482
 Blauöfen, Styrian, 628
 Blistered steel, 873, 878
 Blisters on steel, how formed, 877
 Bloma, 293
 Blomary fire, 640, 644
 manipulation at, 648
 tools of, 651
 Bloom, 643
 Blooming pig iron, 751
 Blooms for sheet iron, 851
 origin of word, 275
 Blossoms, 68
 Blowers, 562, 563
 pressure, 567
 Blowing in a furnace, 360
 Blowpipe to analyze ores, 177
 use of, 932
 Blue carbonate in Pennsylvania, 55
 oven, 293
 Styrian, 628
 Bodemann's combination, 451
 Bog ore, 258
 furnace, 297
 ores, 56, 373
 Boiled iron, when preferable, 747
 Boiler-iron furnaces, 333, 336
 -plate iron, 750, 838, 847
 making, 794
 plates, tensile strength, 891
 Boilers corroded by green vitriol water,
 102
 locomotives with steel, 892
 steel, 888
 Boiling, 661, 667
 cause of, 745
 "Boiling" of iron, 650
 Bolts, saws for cutting, 836
 Bomb ore, analysis of, 463
 "Bombs," 45
 Bone ore, 57
 Booth's analysis of ore, 52
 steel and iron rail, 920
 Borates with protosulphides of iron, 99
 Borax flux, 155
 glass for assaying, 161
 Boremeal, 66
 Boring salt wells, 69
 Borneo iron manufacture, 276
 Boshes, 295
 for puddling furnaces, 697
Boshung, 295
 Bottoms of cast iron for puddling fur-
 naces, 683
 Boxes for charging, 384
 for filling ore, 389
 Bradbury, laminæ of iron, 82
 Braise, 369
Brasqued crucible, 156
 Breaking ore, 370
 advantageous, 268
 "Breathing valves," 903
 Brendon Hills Mines, 47
 Brick lining preferable, 708
 Bricks, composition of, 542
 Brighton ore, 434
Bringing to nature, 645, 650, 665
 Brittle iron, 23
 how caused, 723
 Bromine to separate manganese, 938

- Brown charcoal in Europe, 221
 coal, 186
 charring of, 227
 value of, 244
 hematite, 31, 43, 474
 iron ore, 43
 oxide, 258
 of manganese, 28
 Brownish cinders, 399
 Buckling, 800
 Buff, in iron and nitrogen, 104
 Buhrstone ore, 55
 Building a blast furnace, 347
 a reheating furnace, 825
 material for furnaces, 607
 Bull-dog, 112
 Burden's iron works, 867
 rotary squeezer, 672, 763, 764
 Burmah steel, 871
 Burning lime, proportions for, 154
 of iron, 89
 -on, 821
 Burnt iron, 87, 727
 steel, 88
 Byram mine, 36
 Byrne on tin alloy, 127

 Cadmia, 485
 Cadmium with green vitriol, 101
 Cagniardelle blast machine, 555
 Calama, neutral tersulphate in, 103
 Calcareous carbonates, 54
 ore, 414, 419
 best for gray or foundry metal,
 413
 assay of, 141
 spar flux, 144
 tufa, 145
 Calcined limestone, 447, 527
 Calcining in heaps, 265
 Calcite, 929
 Calcites, tests for, 930
 Calcium, 926
 alloy, 133
 combining with iron, 751
 Calculations of Johnson, 624
 upon the sizes of furnaces and
 blasts, 620
 Calderbank black band, 53
 California marble, 145
 Cam box, 775
 Cambria rolling-mill, 680
 Canada car wheels, 61
 Cannel coal, 189, 191
 Cannon and balls in sea water, 123
 Capped rails, 919, 921
 Carbide, 22
 Carbon, 20, 924
 affinity for, 412, 421
 of iron-clay for, 413

 Carbon—
 amount in iron, 115
 condensed by clay, 421
 burning of, 858
 chemical combinations, 119
 crystallized, 22
 determining in steel, 927
 free in blast furnace, 406
 influences fermentation, 745
 in iron, 723, 724
 and iron, 112
 on iron with phosphorus, 106
 quality of metal depends on, 396
 reducing iron, 735
 removal of, 744
 requisite in iron, 703
 rust of, 19
 steel, 871
 by indirect process, 873
 sulphides heated with, 464
 test, Eggertz's, 904, 907
 to determine, 117
 to reduce silica, 109
 with protosulphide of iron, 98, 99
 Carbonate of lime, determining, 138
 of protoxide of iron, 122
 ore furnaces, 298
 Carbonates as solvents of metallic ox-
 ides, 428
 of alkalis as fluxes, 155
 of iron, 258
 of lime, 27, 929
 Carbonic acid, 20, 938
 gas in air, 18
 oxide for steel, 113
 in roasting, 268
 Carburetted iron, 424
 Carburization, 114
 Care in preparation of ores, 390
 Carinthian gas-puddling furnace, 859
 Carinthia, oxidizing in air, 264
 Caron, on power of manganese, 122
 on steels, 119
 on sulphuretted iron, 121
 Car wheels in Canada, 61
 Case-hardening, 104
 iron, 109, 878
 Castings for rollers, 786
 Cast iron, 112
 bottoms for puddling furnaces,
 683
 columns furnace, 333
 contraction, 84
 from ore, 274
 from the ores, 287
 malleable, 897
 rolls, mending, 821
 steel from, 893
 strength of, 932
 tubular oven, 503

- Cast iron—
 tuyeres, 587
 white and gray, 123
 oven, 293
 Cast-steel, 879
 air furnace, 879
 process of heating, 911
 tensile strength, 891
 Cast and wrought iron, difference, 723
 Catalan forge, 276, 639
 forges, 844
 process for iron, 276
 steel, 871
 Catasauqua blast engine, 573
 furnace, 312, 680
 Cause of boiling, 745
 Causes of bad iron, 497
 of different colored iron, 406
 of scaffolding, 610
 Caustic lime flux, 155
 lime, iron smelted with, 690
 Caution in reduction of ore, 160
 Cement, 541
 " *Cement*," 875
 artificial, 154
 natural, 153
 Cementation, 113, 114
 " *Cementation*," 876
 furnace, 813
 steel, 873
 Centre County, charcoal furnaces, 619
 Chain rods, iron for, 845
 trompe, 556
 Chains for lifting coal, 196
 Chalk, 145
 Chalybite, 47
 Chambers for miners, 77
 Champlain catalan process, 283
 ores, 32, 33
 Change in iron by vibration, 87
 Characteristics of charcoal, 253
 of pig metal, 289
 Charcoal, 25
 absorption of gas by, 223
 of water by, 223
 assays with, 156
 blossoms for sheet iron, 791
 forge cinder, 733
 forges, 693
 hot blast to, 499
 for steel, 877
 furnace, 305
 working, 371
 furnaces of Centre County, 619
 superior to puddled iron, 693
 with protosulphide of iron, 99
 ancient way of making, 209
 characteristics of, 253
 fining with, 893
 moisture in, 387
 Charcoal—
 value of, 244
 working with, 377
 Charcoals, table of, 223
 Charge book, 445
 distributor, 514
 Charge, meaning of, 444
 measure, 384
 amount of fuel for, 388
 Charges at Rochester Works, 473
 distribution of, 481
 for brown hematite, 474
 for fossil ores, 467
 for magnetic sands, 474
 for red hematites, 471
 for titaniferous ores, 474
 number of, 392
 of coal, 388
 recording, 483
 remarks on, 478
 Charging after drawing, 737
 a furnace, 375, 470
 a good proportion for, 462
 at Barrow-in-Furness, 449
 boxes, 384
 Char-oven, 217
 for peat, 225
 Charred peat, 185
 Charring in heaps, 210, 213
 in moulds, 214
 in ovens, 216
 • of bituminous coal, 227
 of brown coal, 227
 of wood, 209
 turf or peat, 224
 wood, remarks on, 220
 Cheap iron, 674
 Cheever-mine, 33
 Chemical analysis of ore, 171
 of peat, 184
 combinations of carbon, 119
 composition of anthracite, 200
 of coal, 189
 difference between cast and
 wrought iron, 723
 knowledge of ores, 481
 properties as alloys, 89
 Chemistry of iron, 17
 Chenot's process, 278
 process for steel, 871
 Chill casting, 109, 118
 rolls, grooved, 822
 Chimney flue, horizontal area, 683
 of furnace, 353
 top, 658
 China clay for assaying, 161
 Chlorides as oxidizers, 740
 dissolve alkalies, 741
 Chloride of lead as a flux, 742
 Chlorine, 258

- Chlorine—
 in ore, 174
 Choice of coal for iron, 255
 Choosing samples, 164
 Chrome iron, 28
 iron sand, 38
 steel, 913
 Chromate of iron alloy, 913
 Chromic iron ore, 934
 Chromium, 28
 alloy, 130
 in chromite, 934
 Cinder, analyses of, 431
 comparison, 733
 in furnace, 380
 of charcoal forge, 733
 plate, height, 377
 plates in rolling, 815
 produced by puddling steel, 896
 refractory, 112
 refinery, 837
 relative degree of fusibility, 425
 too alkaline, 745
 what constitutes a good, 428
 Cinders, a criterion of quality of iron,
 732
 estimation of, 934
 from hematite pig iron, 450
 indications of, 398
 removal of, 401
 Circular ovens for roasting ore, 262
 saws for cutting iron, 835
 Clarence Works roasting furnace, 271
 Clarke, F. W., on dissolving ore, 933
 Classification, assay, of ores, 166
 Clay, 26, 427
 as a flux, 151
 band iron stones, 50
 benefits on iron, 746
 condenses carbon, 421
 iron-stone, 47, 50
 on reheating and rolling, 915
 ore, 416
 ores apt to clinker, 397
 temperature for, 414
 slate, 535
 tensile strength of puddled steel,
 895
 tuyeres, 585, 587,
 Clayey ores, 26
 Clay's process for reducing ore, 278
 Cleaning hoops, 779
 of roasted ores, 265
 ore, 370
 machine for, 266
 the hearth, 381
 Cleveland, cost of rails, 841
 ore, 447
 proportions at, 449
 slag, 449
 Clifton, experiments for steel, 872
 mines, 33
 Works' process, 280
 Clinkers accumulating, 372
 Clinton ore, 48
 Coal, 186
 anthracite, 186, 198
 barrow, 384
 bituminous, 186
 brown, 186
 care in choosing, 255
 charges, 388
 consumption of, 840
 cubical, 190
 distributed in the world, 202
 dry, 186
 fat, 186
 fields, 188
 glance, 189, 191
 lessons from analysis of, 251
 mines, green vitriol in, 102
 mining of, 191
 and ore yard, 369
 price at pits, 203
 shafts, 75
 slate, 190
 splint, 189, 190
 tar, 236
 Coals, density of, 204
 value of, 244
 Coaling, cords in, 182
 Cochrane's method for waste gas, 512
 Coke, 203, 227
 analysis of, 448
 barrow, 384
 consumed at Barrow-in-Furness,
 449
 furnace, gases of, 405
 furnaces, 306, 307, 410
 Belgian, 629
 stoppages of, 614
 value of, 244
 Coking, general remarks on, 238
 in heaps, 227
 in iron retorts, 238
 in ovens, 231
 in rows, 229
 Colburn on breaking of iron, 87
 Colcothar, 91
 manufacture, 102
 Cold blast tuyere, 590
 hammering injurious, 838
 iron hoshes, when best, 703
 pressure injurious, 838
 rolled iron, 822
 rolling, 821
 injurious, 838
 shearing, 836
 short iron, 23, 733
 improved, 700

- Cold—
 shortness from phosphorus, 105
 slags, 444
 steel bar, 119
 Colorado ores, 37
 Colorless crystallized carbon, 22
 Color of cinders, 398
 of sheet iron, 796
 Coloring sheet iron, 798
 Colors of solutions of metallic oxides, 428
 Combination of Bodemann, 451
 Combinations, chemical, of carbon, 119
 Combined water, 937
 Combustion in a blast furnace, 402
 results of, 402
 Coming to nature, 645, 650, 665
 Commercial ores of iron, 30
 Common fan, 560
 force-shear, 833
 salt in refining, 741
 sheet-iron, 795, 847
 Compact earthy carbonates, 61
 ores, objectionable, 411
 Companil, ore of, 279
 Comparative analyses of iron, 691
 economy of hot and cold blast, 525
 effect of blast machines, 598
 value of coal, 251
 Comparison of cinder, 733
 Composition for hardening Damascus steel, 884
 of air, 18
 of anthracite coal of Pennsylvania, 207
 of bricks, 542
 of brown coal, 188
 of Cleveland ore, 447
 of current in furnace, 404
 of forge cinder, 734
 of fuel, 402
 of limestone, 145
 of ores, determining, 136
 of Shurtliff ores, 472
 of Sterling ores, 471
 Compound fluxes, fusibility of, 426
 of Shafhautl, 714
 Compressed air hammers, 806
 Compression of puddled balls, 762
 shingling by, 808
 • Concretions, 63
 Condition of slags, 475
 Conditions of success, 411
 Cone and cup furnace, 511
 furnace, 324
 Conical valve, 594
 Converter, 900
 Connection of iron and cinder, 733
 Consecutive series of rolls, 816
 Constitution of a good cinder, 428
 Construction of a wooden blast machine, 547
 of furnace hearth, 353
 of furnaces, 335
 of puddling and boiling furnaces, 668, 669
 Consumption of blast, 692
 of coal, 840
 of fuel, 425
 Continuous mill, 816
 Contraction of cast iron, 84
 Copake mines, 44
 Copiapo, neutral tersulphate in, 103
 Copper, 939
 alloy, 124
 detected in ore, 175
 needle, 66
 tuyeres, 585
 welding, 85
 and zinc alloy, 126
 Copperas, 101
 mountain, 102
 Correcting influence of sulphur, 255
 Cost of blast machines, 573
 of drifting, 76
 of erecting furnaces, 615
 of furnace, 314
 of iron, 940, 941
 of making rails, 840, 841
 of shaft, 68
 sinking, 76
 Coupling box, 775
 Covering iron to prevent rust, 96
 Covers for crucibles, 160
 Cowper's plan for hot blast, 526
 Coxhoe furnace, 343
 Crane works, 312
 hoisting stock, 386
 Crank, shear moved by, 834, 835
 Cranks, steel, 893
 Cross piling, 838
 Crown Point beds, 34
 Crucible, how placed, 158
 Crucibles, 158, 540
 Cryolite, effect on crucibles, 130
 for assaying, 162
 with malleable iron, 913
 Crystalline iron, 85
 slags, 485
 system of iron, 83
 Crystals of iron, 726
 Crystallized carbonate of protoxide of iron, 47
 Cube ore, 107
 Cubes of iron, 83
 Cubical coal, 190
 iron pyrites, 100
 Cupola furnace, estimate of, 619
 Cupolas, steam jet, 570
 Curl in Damascus steel, 884

- Currents in blast furnaces, 404
 Curved form of furnace, 324
 Cutters, 834
 screwing in, 836
 Cutting bolts, saws for, 836
 iron, shears for, 832
 Cyanide of potassium for reduction of
 ores, 160
 Cylindrical blast current, 508

 Daily history of furnaces, 470
 of Bloomsburg Iron
 Company, 468

 Damascene steel, 639
 Damaskeening silver with gold, 85
 Damascus gun barrels, 883
 steel, 881
 sword blades, 884
 Damask iron, 40
 Dampers to the flue stacks, 683
 Damstones, height, 377
 D'Arcet on fluxes, 134
 David Joy's hammer, 801
 Davy's safety lamp, 76
 Dawe's hammer, 806
 Dead workings, 71
 Debray, protoxide of iron, 90
 Decarbonization by forced air or vapor,
 898
 cast iron, 893
 Deceon, steel from, 885
 Deceptive ore deposits, 72
 Deductions from analyses of cinder, 734
 Deficiencies of run-out fire, 721
 Deficiency of lime, 397
 Degrees for melting, 429
 Delaware bog ores, 56
 Delivering stock, 369
 Density of chrome iron steel, 914
 of coals, 204
 Deoxidation of iron, 872
 Deposits in furnace, 484, 485, 486
 Depth of furnace bottom, 716
 Description of gas furnaces, 856
 of puddling, 685
 Desulphurizing, 99
 Detection of arsenic in iron, 108
 green vitrol, 102
 Determining carbon in steel, 927
 combined carbon, 117
 composition of ores, 136
 constituents of limestone, 148
 titanic acid in iron, 128
 Detmold's improvement in refining, 656
 Dense fibrous bars, 837
 Deville on aluminum, 129
 Diagrams of shafts, 193
 Diameter of top rolls, 815
 Diamond, 22
 Dickerson mine, 36

 Difference between cast and wrought
 iron, 723
 in charcoal and puddled iron, 733
 in puddling and boiling, 668
 in results of stopping the blast, 611
 of ashes in wood, 181
 of pine wood ashes, 181
 Difficulties in blast furnaces, 633
 in furnaces, 399
 in puddling, 688
 in making hot blast, 502
 with fuels, 377
 Digging coal, price of, 196
 Dilatation of iron by heat, 84
 Diluvium, 63
 Dimensions of blast engine, 200
 of grate, 717
 Dimpfel's blower, 563
 Diopside, 486
Direction of mineral deposit, 63
 Directions for assaying, 168
 Direct method of reducing, 280
 process for reduction of iron, 274
 process, steel by, 871
 Disadvantages of Johnson's furnace, 869
 of puddling with steam, 689
 Disaggregation of iron, 87
 Disorders in a blast furnace, 383
 Dissolving ore, 933
 Distribution of charges, 481, 514
 of coal in the world, 202
 of coal in the United States, 202
 Distributor, Escalle's, 514
 of Cochrane, 513
 Prenat's, 514
 Disulphide of iron, 96
 Division of iron manufacture, 274
 Dixon on crucibles, 540
 Dodd's case-hardening furnace, 878
 Dolomite, 929, 930
 Domes, 65
 Door of a puddling furnace, 659
 Double furnace, 670
 with water boshes, 676
 puddling furnaces, 682
 working wooden tubs, 546
 Dove-tail rails, 783
 Dowlais furnaces, 334
 iron works, 632
 Draining, 72
 level, 192
 Drifting, 72
 cost of, 76
 of ore, 79
 Drifts, 71, 74, 75
 Dropping, 608
 Dry air necessary for blast, 368
 assay, 168
 assay of iron ores, 155
 blast receiver, 578

- Dry—
 coal, 186
 Dudgeon's steam hammer, 804
 Dufour on tensile strength of iron, 84
 Duplex steel and iron rail, 920
 Durability of a hearth, 354
 Dutchess County ore, 44
 Dyeing, green vitriol in, 102
- Earle's horizontal and upright air pumps, 570
 Earthy carbonates, 50, 54
 Easily welded iron, 703
 Easton, mines near, 42
 Ebbw Vale furnace, 336
 Eccentric blower, 567
 shear moved by, 833
 Economical working of ores, 420
 Economies of furnace practice, 605
 of the gases, 526
 Economizing fuel, 366
 Economy of fuel, 500
 of hot blast, 501
 Edsall's mine, 44
 Effects as alloys, 89
 of moist atmosphere, 631
 of reheating and rolling, 915
 Efflorescence, green vitriol in, 102
 Eggertz on copper alloy, 124, 125
 Eggertz's carbon test, 904, 907
 Eggshell furnace, 324
 Eisenerz furnace, 298
 mines, 47
 Eisensinter, 107
 Ekman, steel by arsenic, 109
 Elba, natural magnets in, 38
 Electro-negative elements in coal, 189
 Electro-deposited iron, 82
 Electrolysis, 82
 Electro-positive elements in coal, 189
 Elements in air, 18
 of pig iron, 706
 Elevation of a puddling furnace, 657
 of Wagner's rolling mill, 817
 Ellershausen process, 283, 860, 865
 Elliptical siphons, hot blast, 510
 Emery quarries, 37
 Employment of reheating furnaces, 827
 End of a binder, 352
 England, articles for malleable iron, 114
 black band ores, 50
 English coke iron, 873
 coke ovens, 235
 round oven, 503
 Erecting furnaces, cost of, 615
 Erection of furnace, 605
 of works for making sheet iron, 852
 Erzberg mines, 47
 Escalle's distributor, 514
 Estimate of a cupola furnace, 619
 Estimates for building stack, 358
 Estimation of ores, slags, and cinders, 934
 European furnaces, 364
 Europe, blowery fires, 651
 iron, industry of, 626
 natural magnets in, 38
 Evaporative power of American fuel, 245
 Excellence of chrome iron steel, 913
 Excess of blast objectionable, 629
 of lime, 397
 of salt injurious, 742
 Existence of carbon in iron, 117
 Exmon mines, 47
 Expense of bellows, 546
 of building stack, 358
 of peat, 185
 Experiments by Sefstrom, 116
 for steel, 872
 on blast, 482
 in puddling, 702
 on armor plates, 87
 on chromium alloy, 131
 on iron free from carbon, 130
 on melting point, 429
 on strength of cast iron, 932
 with chromium, 132
 with copper alloy, 125
 with ores, 465
 with platinum, 129
 with steel, 887, 890
 Explosions from hydrogen, 21
 Exploring, 67
 Exposition, rolls in, 823
 Exposure injures charcoal, 370
 Expressing result of analysis, 938
 Extraction of ores, 71
 Eye of a binder, 352
- Faces of anvils, 760
 of hammers, 760
 Facts in blast furnaces, 409
 Fagersta works, 906
 Fairbairn & Hodgkinson, experiments, 932
 Fan blast machines, 559
 blowers, 262
 Fans, applications of, 565
 Faraday on alloys, 129, 130
 on regenerating gas furnaces, 855
 on wootz, 881
 Farmer's blower, 563
 Fastening steel cutters, 836
 Fat coal, 186
 lime, 152
 Feldspar, 931
 Ferric acid, 24, 95
 Fermentation, advantage of, 747
 of iron, 745

- Fern leaves in ore, 51
 Ferrates, 24
 Ferrate of soda, 95
 of baryta, 95
 Ferrites of alkalies, 90
 Ferruginous shale for fluxing, 152
 Ferry hill furnace, 343
 Fibre of iron injured, 838
 Fibrous bar iron, 673
 character of iron, 837, 838
 iron, 85, 751
 railroad iron, 703
 Fillers, 478
 Filling a furnace regularly, 383
 furnaces, 387
 Finery, 719
 advantage of, 749
 a link between blast and puddling
 furnace, 749
 cinder, analysis of, 748
 fire, 652
 Fining with charcoal, 893
 Finland iron manufacture, 277
 Fire-brick, 533, 536
 lining, when preferable, 703
 Fire-clay, 426, 541
 for assaying, 161
 Fire in steel furnace, 876
 kindling in furnace, 374
 Fire-place, 647
 Fire-proof material, 533, 534, 535
 Fish-egg ore, 42, 48
 Flame of tunnel head indications, 399
 Flames, indications of, 399
 Flange, irons 837
 Flat iron, grooves for, 781
 rails, 783
 rollers, 770
 water tuyeres, 588
 Flattening the tuyere, 690
 Flint-glass flux, 155
 Flue stacks, dampers to, 683
 Fluoride of calcium for assaying, 162
 of calcium and iron, 106
 Fluor spar for assaying, 162
 on iron, 106
 Flux, definition of, 144
 for aluminous ore, 139
 for calcareous ore, 419
 for iron, 85
 for silicious ore, 139
 lime as, 27
 Fluxes, 712, 742
 application of, 371
 for assaying, 160
 for blast furnace, 144
 object of, 162
 phosphates as, 739, 740
 proportion of, 165
 refractory nature of, 391
 Fluxes—
 special notice of, 426
 theory of, 134
 varieties of, 144
 Fluxing, 647
 materials, multiplying, 454
 Fly wheels, 776
 Forced air, decarbonization by, 898
 Force-shears, 832
 -shear, common, 833
 Foreign matter in ores, influence of, 412
 matters in iron, 723
 matter in limestone, 146
 Forge, catalan, 276, 639
 cinder, 732
 contains alkali, 732
 German, 643
 fire, 639, 643, 644
 Persian, 637
 hammers, 753
 Forges, catalan, 844
 Forging, 753
 Forms of blast machines, 555
 Formula of Lindauer, 621
 Fossil ore in Blossburg, 57
 charges for, 467
 ores, 48
 Foundations of furnaces, 606
Fonte truitée, 117
 France, coke ovens in, 232
 Franklinite, 38
 ore, 35
 Fremy on alloys, 131
 French coke oven, 238
 trout iron, 117
 Fresenius' plan to analyze ore, 177
 Fritz & Moore blower, 570
 Fritz's red-short iron, 839
 Front view of furnace, 349
 Fuel, 160, 178
 affects color of sheet iron, 797
 amount of, for a charge, 388
 composition of, 402
 consumption of, 425
 economizing, 366
 economy of, 500
 for heating ovens, 829
 general remarks on, 201
 heat liberated by, 242
 influence of, 717
 in Styria, 704
 saved in anthracite and coke fur-
 naces, 501
 size of, 388
 Fumes of sulphur thrown off, 401
 of zinc, 484
 Furgeon, 751
 Furnace, 156
 arches, 350
 at Catasauqua, 312

Furnace—

at Cold Spring, 301
 at Middleboro, 271
 at Reading, 311
 best form, 315
 binders, 352
 blast, 295
 blowing in a, 360
 bog ore, 257
 building, 347
 cast steel, 879
 charcoal, 305
 charging, 375
 chimney, 353
 cone, 324
 curved form of, 324
 deposits, 484, 485, 486
 disorders in a blast, 383
 for rich ores, 422
 for steel, 440
 front view of, 349
 glass, 486
 Glendon, 323
 ground-plan of, 348
 Hartz mountains, 295
 hearth, 353
 hearth of a blast, 374
 Hindoo, 276
 Indian, 881
 lining, 351
 Johnson's, 868
 keeping, 378
 lining of, 373
 location of, 348
 Lonaconing, 306
 Melapane, 296
 modern charcoal blast, 302
 mortar for, 350
 of cementation, 873
 of Morgans', 347
 operation in a, 407
 Penna. charcoal blast, 302
 pillars, 350
 practice, economies of, 605
 regenerative gas, 855
 regular filling of, 383
 salamander, 291
 Scranton, 320
 Sheffield, 873
 Silesia, 296
 spathic ore, 297
 stack, 357
 stonecoal, 310
 Stuckofen, 277
 sulphur in, 442
 theory of blast, 402
 throat of, 364
 tunnel head of, 364
 Ulverstone, 629

Furnace—

with cooled hearth, when disadvantageous, 699
 without a hearth, 422
 working a charcoal, 371
 Furnaces, Acklam, 342
 anthracite, 310, 410
 at Barrow-in-Furness, 450
 at Crane works, 312
 calculations upon sizes, 620, 626
 carbonate ore, 298
 case-hardening, 878
 cast iron columns, 333
 coke, 306, 307, 410
 construction of, 335
 cost of erecting, 615
 Dowlais, 334
 Eisenerz, 298
 egg shell form, 324
 erection of, 605
 estimate of a cupola, 619
 ferry hill, 343
 filling, 387
 fluxes for blast, 144
 for pig metal, 291
 high, 337
 Hyanges, 308
 inspecting blast, 629
 later forms of, 295
 management of blast, 373
 of boiler iron, 333
 of Europe, 364
 of Monkland, 339
 Ormsby, 341
 Phoenixville, 313
 positions of, 608
 puddling, 656
 reheating, 824
 relative cost of, 314
 remarks on, 362
 reverberating for roasting, 262
 roasting ore in, 259
 Sweden, 299
 variations in, 409, 410
 Fusibility, increased, 730
 of cinder, relative degree of, 425
 of compounds, 426
 Fusible iron, 423, 707
 Galleries, 71
 in coal veins, 196
 Galvanizing, 126
 iron, 722
 Garrett's analysis of ore, 52
 Ganister, 903
 Gases absorbed by charcoal, 223
 in a blast furnace, 404
 nature, &c., of the, 526
 waste, 487
 utilization of, 681

- Gas furnace, regenerative, 855
 pipes, iron for, 703
 puddling furnace, Corinthian, 859
 Gasometer bellows, 557
 Gathering coal tar for coke oven, 236
 Gangue, 477
 definition of, 161
 Gaunlett's pyrometer, 521, 524
 Gellivera mountain, 31
 General remarks on blast machines,
 597
 on cylinder blast machines,
 551
 on refining, 719
 Geodes of sulphide of iron, 57
 Geological teaching, 64
 Geology of black band ores, 50
 of brown hematite, 44
 of fossil ores, 49
 of franklinite, 39
 of iron ores, 38
 of red hematite, 40
 of spathic ore, 47
 Georgia, brown hematite, 46
 ores, 36
 German blast furnace, 301
 forge, 643
 iron, 115
 method of firing, 70
 mixing of ores, 391
 steel, metal for, 439
 Germany, coke ovens in, 232
 Glass, 25, 134, 135
 for assaying, 160
 from blast furnace, 486
 Glassy cinder, 735
 Glance coal, 189, 191
 Glazed cinders, indications of, 398
 Glendon furnace, 323
 Gold alloy, 129
 coheres with silver, 85
 in iron pyrites, 97
 sulphide of, 97
 with pyrites, 101
 Good blast furnace cinder, 161
 Gothite, 45
 Grade of iron varied, 143.
 Grades of cast iron, 118
 Graham on sesquioxide of iron, 93
 Granular magnetite, 36
 Graphite, 22, 117, 123, 486
 Graphitic carbon, 22
 surface on iron, 798
 Grate, dimensions of, 717
 of reheating furnace, 826
 Gray anthracite iron, 714 ■ P
 carbonate in Kentucky, 55
 cast iron, 115, 123
 charcoal iron, 714
 cinders, 398
- Gray—
 iron, 117, 298
 metal, 400
 calcareous ore best for, 413
 pig iron best for puddling, 702
 varieties of iron, 688
 Great Meadows silver mine, 108
 Green cinders, 398
 Green vitriol, 101
 Grog, 159
 Ground-plan of a wood-drying oven,
 220
 of furnace foundation, 348
 of heating-oven, 832
 of interior of a mine, 78
 Grooved chill rolls, 822
 rolls, sweep, 823
 Grooves in roughing rollers, 767, 769
 for plate iron, 781
 for T rails, 785
 Guards, rolling, 778
 Gun-barrels, Damascus, 883
 Gunpowder hammer, 807
 Gurlt on white iron, 120
 Gypsum, 173
- Hall on preserving iron from rust, 96
 Hammers, compressed air, 806
 David Joy's, 801
 forge, 753
 improvements in, 801
 Hammer, gunpowder, 807
 Nasmyth, 801
 Schneider, 801
 steam, 757, 759
 tilt, 753, 754
 Hammered steels, 119
 Hammering does not destroy crystalline
 form within, 86
 improves iron, 814
 Hammerslag, 94, 647
 Hand-drill, 66
 -shears, 832
 portable, 833
 Hard alloy, 131
 and soft wood, 179
 charcoal, saving by, 501
 Hardening composition for Damascus
 steel, 184
 of lime under water, 153
 Hartz Mountains' furnace, 295
 natural magnets in, 38
 Hauling coal to mouth of pit, 197
 the wood to the hearth, 210
 Hausmannite, 28
 Hawkins' patent for steel, 871
 Haywood's piling, 838
 Heaps, charring in, 210, 213
 coking in, 227
 roasting in, 263

- Hearth, 376
 cleaning, 381
 furnace without, 422
 of a blast furnace, 374
 of furnace, 353
 of reheating furnace, 826
 -stones, 354
- Heat as fuel, 182
 definition of, 242
 from guns in sea water, 124
 liberated by fuel, 242
 waste, 487, 528, 529
- Heated blast for puddling, 690
- Heating of nitrogenous matters, 104
 oven for sheet iron, 831
 ground-plan of, 832
 ovens, 829, 830
 stove applied to puddling furnace, 672
 stoves, 718
 value of coal, 249
- Heaton's cast steel process, 911
 method for steel, 896
- Heavy bar iron, 703
 squaring ends, 788
 bar rollers, 782
 blast reduces yield, 383
 sheet iron, 852
- Height of a furnace stack, 364
 of damstone and cinder plate, 377
 of furnace top, 76
- Hematite, 258, 887, 934
 cinders from, 450
- Hematites, charges, 471
- Hematized outcrop, 46
- Hemp ropes for lifting coal, 196
- Henry, analysis of spiegeleisen, 119
- Hessian crucible, 158
- Hewitt, report on rolls, 823
- Hibernia mine, 36
- High bloomery furnace, 277
 furnaces, 337
 -oxide of iron, 19
 high temperature, utility of, 521
- Himalayan Mountains, iron manufacture, 276
- Hindoo manufacture of iron, 276
 steel, 871
- History of anthracite coal in iron-working, 198
 of hot blast, 501
- Hoist, air, 602
 air engine, 605
 steam, 605
- Hoists, Armstrong's hydraulic, 601
 on inclined planes, 601
 water, 601
- Hoisting stock, 369, 386
- Hokendaqua blast engine, 573
- Homogeneous metal, 886, 888
- Hoop iron, 703, 780, 845
- Hoops, polishing, 779
- Horizontal area of chimney flue, 683
 blast engine, 574
 cylinder blast machine, 549
 gallery, 70
 pipes, 508
 section of a furnace hearth, 357
- Hornblende, 931
- Horton's use of gases, 520
- Hot air in puddling, 500
 blast apparatus, 489
 economy of, 501
 for charcoal forge, 695
 history of, 501
 ovens, 487
 pyrometer, 503
 Scranton, 504
 stoves, 339, 340
 theory of, 494
 to charcoal forges, 499
 tuyere, 590
 Wasseraffingen, 508
 -shot iron, 60
 slags, 444
- Howell's patent for steel, 887
- Hyanges blast furnace, 310
 furnace, 308
 puddling furnace, 673
- Hydrated ores, 29
 oxide of iron, 60
 sesquioxide of iron, 43, 92
- Hydrate oxide, 258
- Hydrochloric acid, solvent, 91
- Hydraulic hoists, 601
 limes, 152
 limestone, 929, 930
- Hydrogen, 20
 for steel, 113
 iron by, 81
 in air, 18
 on protosulphide of iron, 97
- Hydro-oxygen furnace, 855
- Hydrous, 29
 sesquioxide, 31
- Hygroscopic moisture, 937
- Ides, 21
- Igneous rocks, 63
- Ignition, spontaneous, of iron, 89
- Illustration of theory of blast furnace, 402
- Ilmenite, 934
- Imitating cinder, 432, 433
- Immediate cause of scaffolding, 609
- Importance of piling iron, 848, 849
- Improper building material for furnaces, 607
- Improved fan, 561

- Improvement in hot blast of Thomas
 and Laurens, 508
 of iron by puddling, 698
 of iron by salt, 741
 of Lurmann, 343
 of metal, philosophy of, 749
 of pig iron by cold water, 498
 Improvements in hammers and rolls,
 801
 in hot blast, 501
 in puddling, 675
 furnaces, 680
 in rolls and rolling, 815
 Improving iron, 710, 711, 712, 722
 Impure carbon, 25
 Impurities complicate manufacture of
 iron, 274
 in green vitriol, 102
Inclination of deposits, 63
 Inclined planes, hoists on, 601
 shafts, 75
 Incorporation of other iron in puddling,
 693
 India method of iron manufacture, 275
 Indiana earthy carbonates, 54
 bog ores, 56
 Indian method of working steel for sound
 blades, &c., 883
 steel, 129, 880
 Indication from cinders, 398
 of flame, 399
 Indirect extraction of iron, 287
 process for reduction of iron, 274
 steel, 873
 Inferior metals for puddling, 695
 Influence of foreign matter in ores, 412
 of fuel, 717
 Ingots, steel, 902, 903
 Inkey taste from green vitriol, 102
 Insecure foundation of furnaces, 606
 Inspecting blast furnaces, 629
 Instruments for mining, 65
 Introduction to treatise on steel, 870
 Introductory practice of fluxes, 134
 Inventor of water tuyere, 592
 Investigation of Weisse and Ech, 632
 Iron, amount of carbon in, 115
 and arsenic, 107
 arsenides, 107
 burnt, 87
 by hydrogen, 81
 and carbon, 112
 chemistry of, 17
 chromate of, alloy, 913
 chrome, steel, 913
 clay, affinity for carbon, 413
 cold rolled, 822
 cold-short, 23, 733
 crystalline and fibrous, 85
 from heat, 86
 Iron—
 cylinder blast machines, 548
 decomposes water, 96
 dilatation by heat, 84
 for nails, 853
 for polishing plate-glass, 91
 industry of Europe, 626
 magnetism of, 84
 melting point, 84
 mining, 62
 mottled, 117
 needle, 66
 and nitrogen, 104
 and fluorspar, 106
 in phosphate of lime, 106
 ores, 30
 roasting, 257
 and oxygen, 89
 and phosphorus, 104
 powder, 81
 protosulphide, 97
 protoxide, 90
 pyrites, 100
 pyrophoric, 89
 rust, 19, 95
 scale, 94
 sesquioxide, 90
 smelting of, 99
 special properties of, 81
 specific heat of, 84
 sulphides, 96
 and sulphur, 96
 tensile strength, 84
 theoretic metallurgy of, 17
 and water, 95
 wire burned, 104
 with carbon, action of sulphur on,
 120
 Irondale, 35
 Ironhill, 35
 Ironton mines, 44
 Isle of Wight, black-band ores, 50
 Istrian, broken plates from, 87
 Jackson mountain mines, 42
 Janoyer's experiments with phosphorus
 and iron, &c., 121
 Jayville Bed, 33
 Jet cupolas, 570
 Johnson on American coals, 241
 Johnson's analyses of anthracite, 207
 calculations, 624
 continuous mill, 816
 furnace, 868
 Johnstown (Pa.), coking at, 240
 Joy's hammer, 801
 Junction shaft, 775
 Kalium, 29
 Kaolin, 931

- Karsten, action of sulphur on iron, 120
 carbon in iron, 115
 iron not affected by phosphorus, 105
 on alloys, 128
 on aluminum in steel, 180
 on cast iron, 116
 on copper alloy, 124
 on tin alloy, 126
- Keeping accounts, 839
 a furnace, 378
- Kennelburn black-band, 53
- Kent (Conn.) ores, 44
- Kentucky black-band ores, 51
 brown hematite, 46
 carbonates, 55
 earthy carbonates, 54
 fossil ores, 49
 peculiar ore, 58
- Key of a binder, 352
- Kilns for charcoal, 210
- Kindling fire in furnace, 374
- Kinsey's improvement on Dudgeon's hammer, 806
- Kirkless Hall, slag at, 450
- Kirkaldy's experiments, 915
- Kirwan on fluxes, 135
- Knowledge important in making iron, 445
 of composition of ores, 135
- Königshütte, 484
- Krämer, nitrogen in iron, 83
- Krauss & Co.'s pyrometer, 523
- Labrador mines, 38
- Lackawanna Company, 458
- Lake Champlain mines, 33
 natural magnets, 38
 ores, 23
 Superior peculiar ores, 57
- Landrin, analysis of steel, 924
- Laplace, dilatation of iron by heat, 84
- Large forge hammer, 758
- Later forms of furnaces, 295
- Lavoisier, dilatation of iron by heat, 84
- Law of blast pipes, 594
 mechanical of blowers, 569
- Lead alloy, 128
 with protosulphide of iron, 98
- Leaky tuyere, loss by, 600
- Lemery's volcanoes, 97
- Lenticular ore, 42, 48
- Lessons from analysis of coal, 251
- Level, to drive, 70
- Lever squeezer, 761
- Lewis's cast rolls, 823
- Liebig on alloys of nickel, 128
- Lifting coal in a shaft, 196
- Lignite, 186
- Lime, 26
 absorbs sulphur, 428
- Lime—
 as a flux, 27
 carbonates of, 929
 charge of, 527
 deficient, how known, 397
 flux, 144
 for assaying, 162
 in excess detected, 397
 in ore detected, 172
 in too great quantity produces white iron, 397
 in wood ashes, 180
 to prevent iron rusting, 96
 varieties, 152
 when objectionable, 439
 with protosulphide of iron, 99
- Limestone a good flux, 430
 analysis of, 148, 461
 calcined, 447, 527
 hydraulic, 929, 930
 sampling, 480
 testing for, 136
 varieties, 152
- Limestones, 145
- Limonite, 43, 934
- Lindauer's formula, 621
- Lining, 32
 for crucibles, 159
 of furnace, 351, 373
- Little Iron Mountain, 36
- Localities of chrome iron, 28
- Location of a furnace, 348
 of blast machine, 598
 of charcoal forges, 694
- Locomotives, steel for, 892
 with steel boilers, 892
- Lodes, 63
- Logan iron works, 751
- Lomorrostro, ore of, 279
- Lonacoming furnace, 306
- Longest period of stopping the blast, 613
- Looking-glass iron, 38
- Loss by a leaky tuyere, 600
 in puddling, 718
- Louth's three high rolls, 819
- Lyon, tests of steel rails, 919
- Lucas' malleable cast iron, 897
 patent for steel, 871
- Lurmann's improvement, 343
- Machine, blast, 367
 for cleaning ore, 266
- Machinery for sheet iron, 792
- Machines, blast, 542, 547, 548, 555
 fan blast, 559
- Macintosh's patent, 282
- Mackenzie's eccentric blower, 567
- Madagascar iron manufacture, 276
- Madras iron, 873

- Magnesia detected in ore, 175
 in ore detected, 173
 from limestone, 149
 Magnesian limes, 929, 930
 Magnesium, 926
 alloy, 134
 Magnetic mines, 33
 ore, 31, 33, 415, 935
 ores, 23
 for charcoal forge, 694
 oxide of iron, 31, 59, 94, 257
 pyrites, 101
 sands, 474
 malleable iron from, 275
 Magnetism of iron, 83
 Magnetite, 31, 934
 Magnets, natural, 38
 Magnes, reduction of iron, 89
 Main object of fluxes, 162
 Making boiler-plate, 794
 charcoal in heaps, 213
 iron, Persian mode, 637, 638
 malleable iron, 860, 864, 865
 rails, cost of, 840, 841
 sheet iron, 791
 steel, 876
 Malleability affected by phosphorus, 105
 Malleable cast iron, 897
 iron, 114
 direct from ore, 274
 from magnetic sand, 275
 making of, 860, 864, 865
 manufacture of, 636
 steel from, 873, 885
 with aluminum, 913
 Mallet, 65
 Mallet's process for tin on iron, 127
 Management of Bessemer process, 900
 of blast furnaces, 373
 Manganese, 27, 926
 as an oxidizer, 742
 detected in ore, 176
 in iron, 727
 in ore detected, 172
 iron ore, 57
 from Tennessee, 57
 and phosphorus on iron, 106
 power to eliminate phosphorus, 122
 and sulphur in slags, 117
 to extract silicon, 122
 to improve iron, 736
 with protosulphide of iron, 99
 Manilla ropes for lifting coal, 196
 Manipulation at a bloomery fire, 648
 in furnace with water boshes, 678
 for roasting, 259
 of forge fire, 641
 Manometer, 493, 595
 Manufacture of Indian and steel, 881
 of malleable iron, 636
 Manufacture—
 of sheet iron, 850
 Marble, 145
 Hill mines, 42
 Marquette ores, analysis, 37
 Mariazell, plan of roasting in, 269
 Martien's process for steel, 898
 Maryland, black band, 51
 brown hematite, 46
 carbonates, 55
 Masses, 63
 of iron ore, 31
 Material consumed for one ton of coal,
 815
 for a hearth, 354
 for furnace building, 607
 refractory, 533, 534, 535
 Materials for artificial fluxes, 713
 for hearths, 374
 for multiplying fluxing, 454
 Matteucci, magnetism of iron, 83
 Maynard, analyses, 867
 McGinnes' vein, 51
 McIntyre on furnaces, 315
 Measure for charges, 384
 of blast, 595
 Measurement for valuing coal, 197
 of coal by weight, 198
 of coal in United States, 203
 Measurements, pyrometrical, 493
 Measuring charges, 387
 Mechanic's Journal on steel, 890
 Mechanical law of blowers, 569
 processes in puddling, 684
 Medicines for making steel, 896
 Meidenger, ammonia iron in, 83
 Melapane furnace, 296
 Melted iron too long in furnace, 396
 Melting degree, 429
 of cinder too early, 737
 point, 429
 of iron, 84
 Mending cast iron rolls, 821
 Merchand, oxide of iron, 89
 Merchant iron, 703, 704
 rollers, 776, 777
 rolling mill, 776
 Merrick's account of the Joy hammer,
 803
 Metal for German steel, 439
 for puddling, 696
 homogeneous, 886, 888
 quality depends on carbon, 396
 refined, yield of, 839
 remarks on Bessemer, 916
 tempering, 750
 yield of, 476
 Metallic carbon, 22
 oxides, dissolved by alkalis, 428
 by silicates, 428

- Metallic—
 sponge, 278, 872
 Metalloid, definition of, 288
 Metallurgy of iron, 17
 Metals for charcoal forge, 694
 melting point of, 429
 smelted by charcoal from phosphu-
 rets, 713
 Metamorphic rocks, 63
 Meta-sesquioxide of iron, 93
 Meteorolites, iron in, 31
 Method, dry, for assay of ores, 155
 of arranging hearthstones, 355
 of determining carbon in steel, 927
 constituents of limestone, 148
 titanic acid in iron, 128
 of dissolving ore, 933
 of reduction of ore, 160
 of running Lurmann's improve-
 ment, 345
 Methods in furnace erection, 605
 of refining, 690, 721
 of working coal veins, 194
 Micaceous iron ore, 90
 red hematite, 42
 Michigan bog ores, 56
 ores, 37
 Mill bars, 684, 847
 continuous, 816
 rolling, 776
 tools in a rolling, 842
 Wagner's universal rolling, 816
 Miller, analyses of iron, 114
 cubes of iron, 83
 on conversion into steel, 913
 Millerite, 42
 Milwaukee, mines near, 42
 Mine dust, 154
 Mine of supposed silver, 108
 Mineral fuel, 182
 Mineralogy, 63
 Mining, 70
 of coal, 191
 of iron ore, 62
 tools, 65
 Mispickel, 108
 Mississippi, pyrites and gold, 101
 Missouri, brown hematite, 47
 peculiar ores, 57
 Mixing iron, 710
 of ores, German method, 391
 ores, 444
 ores and fluxes, 371
 Mixture of fluxes and ores, 391
 ore and flux, important, 397
 of ores, 414, 415, 416
 of ores, profitable, 422
 Mixtures, refining by, 692
 Mode, Persian, of making iron, 637,
 638
 Modern application of hot blast, 501
 charcoal blast furnace, 302
 practice of roasting, 268
 Modes of existence of carbon in iron,
 117
 of roasting ore, 259
 Modification of bloomary process, 751
Moellering, 393
 Moffat's analysis of coal, 209
 Moist atmosphere, effects of, 631
 ores, 29
 Moisture, hygroscopic, 937
 in a blast furnace, 631
 in air, 18, 632
 in charcoal, 387
 Möller, 630
 Monkland furnaces, 839
 Monster blast furnace, 339
 Morgan bank ores, 36
 Morgan's blast furnace, 347
 Moriah beds, 34
 Morin on tenacity, 915
 Morrell, cost of rails, 840
 Morris County, N. J., ores, 34, 35
 Mortar for furnace, 350
 Morveau on aluminum, 26
 Motive power for furnaces, 367
 Mottled iron, 117
 Mounds, charring in, 214
 roasting in, 262
 Mouse covered with pyrites, 100
 Mouth-pieces of blastpipes, 583
 Mount Hope mine, 36
 Mount Pleasant mine, 36
 Mount Savage works, 307
 Movable hand shears, 832
 Muck as a fuel, 226
 Müller, analysis of ore, 939
 Mullica Hill, vivianite, 106
 Multiplying fluxing materials, 454
 Mushet, experiments on ores, 413
 on copper alloy, 124, 125
 on fluxes, 135
 on titaniferous sand, 128
 on vanadium, 134
 on wood charring, 222
 fluxes, 139
 patent for steel, 871
 steel, 885, 915
 table for fluxes, 142
 Nail plates, manufacture of, 704
 shears for cutting, 834
 Nails, 853
 iron for, 704, 706
 Nasmyth hammer, 801
 Native refractory stones, 534
 Natrium, 29
 Natural cement, 153
 magnets, 38

- Nature of the gases, 526
 Necessity for roasting ore, 257
 of analyzing limestone, 146
 of good ore for a charcoal forge, 695
 of knowledge of ores, 135
 Needle of miner, 66
 Neilson's improvement in hot blast, 501
 Nests, 63
 Neutralizing silex, 733
 Neutral tersulphate of iron, 103
 Neuberg, Bessemer process in, 907
 steel, tensile strength, 911
 New England nail plates, 853
 New Jersey bog ores, 56
 mines, 35
 vivianite, 106
 Newton's patent for steel, 871
 New York bog ores, 56
 mines, 33
 fossil ores, 48
 peculiar ores, 57
 Nickel alloy, 128
 Nickeliferous magnetite, 36
 Nitric oxide absorbed by green vitriol, 101
 Nitrogen, 26, 925
 in air, 18
 in iron, 83
 Nitrogenous matters heated with iron, 104
 Nitrogen in iron, 104
 Nodules, 63
 Norway, roasting ore in, 262
 Nordhausen sulphuric acid, 101
 North Carolina brown hematite, 46
 mines, 36
 Nose on tuyere, 379
 Nostrums for making steel, 896
 Nozzles of blast pipes, 583
 Number of charges, 392
 of tuyeres, 393, 482
 Oak wood, best, 179
 Object desired in flux, 142
 of analysis, 136
 of fluxes, 162
 of refining iron, 732
 of roasting ore, 257, 497
 of the iron manufacturer, 390
 Occasions of scaffolding, 610
 Octahedra of iron, 83
 Ogden mine, 36
 Ohio bog ores, 56
 brown hematite in, 44
 brown hematite, 46
 carbonates, 55
 earth carbonates, 54
 peculiar ore, 58
 Oker, sulphuric acid works, 103
 Olive-green cinders, 398
 Oolite, ore in, 44
 Oolitic fossil ore, 48
 Open air roasting, 263
 Opening of galleries in coal veins, 196
 Openness of tunnel head, 512
 Operation in a furnace, 407
 Operation in puddling furnace, 662
 of artificial fluxes, 713
 Orchard mine, 36
 Ore, analysis of, 433, 434, 463, 867
 argillaceous, 936
 at Barrow-in-Furness, 449
 boxes for filling, 389
 drifting of, 79
 heap, 265
 necessary to be analyzed, 135
 quantity to be used, 163
 roasting, 257, 259
 simple test for, 174
 size of, 389
 steel from, 811
 Oregon mines, 37
 Ores always imperfect, 423
 analyses of, 935, 936
 chemical knowledge of, 481
 dissolving, 933
 dry assay of, 155
 economical working, 420
 estimation of, 934
 experiments in mixing, 465
 for charcoal forge, 694
 for special purposes, 711, 712
 fossil, 48
 in New Jersey, 32
 in Pennsylvania, 936
 magnetic, 23
 mixing, 444
 of iron, 30
 profitable when self-fluxing, 418
 refractory, 372
 theory of reduction, 405
 theory of roasting, 267
 Ormsby furnaces, 341
 Osmund furnace, 277
 Out-door coking, 240
 Outside lining of puddling furnace, 680
 Oven, blue, 293
 English round, 503
 for sheet iron, 831
 ground-plan of heating, 832
 Mayer's, 516
 Stück, 291
 Wasseralfingen, 508
 cast, 293
 cast-iron tubular, 503
 Wulf's, 291
 Ovens, charring in, 216
 coking in, 231
 heating, 829, 830

- Ovens—
 hot blast, 487
 roasting ore in, 259
 Overman on building furnaces, 347
 on malleable iron, 636
 on western furnaces, 314
 Owen's analysis of ore, 37
 Oxford furnace, 35, 681
 Oxidation necessary, 257
 of iron, 747
 Oxide of aluminum, 26
 of copper process, 940
 of lead as a flux, 742
 of silicon, 24
 of zinc manufacture, 485
 Oxides of iron, 19
 of manganese, 27
 Oxidizers, chlorides as, 740
 sulphates as, 742
 Oxidizing by air, 264
 Oxygen, 18, 19
 and iron, 89
 introduced into iron, 911
 Oxygenated iron, 143
 Oyster shells as a flux, 145
- Palladium alloy, 129
 Paraffine for steel, 113
 Park on methods for steel, 885
 Parry on silicon and pig iron, 111
 on sulphur in slags, 99
 Passaic County, N. J., ores, 35
 Patent powders for making steel, 896
 Patents for alloying iron, 128
 for steel, 871, 872, 887, 898, 899
 Paxton on stopping the blast, 613
 Payen on preserving iron from rust, 96
 Peat ashes, 183
 as a fuel, 226
 bogs in United States, 201
 charcoal, value of, 244
 char-oven for, 225
 charring, 224
 in Europe, 201
 prepared for iron-working, 204
 value of, 244
 Peculiar action of alumina, 427
 ores, 56
 Pele's hair, 486
 Peligot's plan, for pure iron, 81
 Penetrating rock, 69
 Pennsylvania black-band ores, 50
 charcoal blast furnace, 302 ●
 blomary fires, 644
 bog ores, 56
 brown hematite in, 44, 46
 composition of anthracite coal, 207
 earthy carbonates, 55
 fossil ore, 57
 fossil ores, 48
- Pennsylvania—
 iron beds, 35, 36
 Iron Works, 471
 ores in, 936
 peculiar ores, 57
 Percy, carbon in iron, 116
 experiments for steel, 113
 heat of iron, 84
 iron by electrolysis, 82
 octahedra of iron, 83
 on argillaceous ores, 50
 on crucibles, 159
 on hydrated sesquioxide of iron, 93
 on iron and water, 95
 on magnetic oxide of iron, 94
 on mottled iron, 117
 on Mushet's steel, 887
 on precipitated protosulphide, 97
 on preventing rust, 96
 on protosulphide, 98
 on pyrophoric iron, 89
 on silicate of lime, etc., 99
 on steel nostrums, 896
 proportion of fluxes, 165, 167
 steel by arsenic, 109
 strength of steel, 914
 Percy's experiments on cast iron, 116
 on chromium, 131
 with carbon and silica, 109
 with spiegeleisen, 122
 plan for pure iron, 81
 solution of green vitriol, 102
 Perfect ores impossible, 423
 Permanganic acid, 27
 Peroxide of iron, 19
 of manganese, 27
 Permanganate of potash, assay, 170
 Persian forge fire, 637
 mode of making iron, 637, 638
 Petroleum in reduction of ore, 282
 Philosophy of Ellershausen process, 863
 of metal improvement, 749
 Phoenixville furnaces, 313
 Phosphate of lime bed, 34
 on iron, 106
 with iron, 23
 Phosphates as fluxes, 739, 740
 Phosphide of iron, 104
 Phosphide in Russia sheeting, 798
 Phosphoric acid, 23, 930, 933, 937
 in limestone, 150
 Phosphorus, 23, 925
 absorbed by alumina, 428
 detected in iron ore, 176, 177
 and iron, 104
 in ore detected, 172, 173
 on iron with carbon and sulphur,
 121
 Phosphurets, metals from, 713
 of iron, 258

- Physical condition of slags, 475
 Pick, 65
 Pickling, 126
 Pig iron, 749
 bad, 736
 blooming, 751
 from sulphurous ore smelted
 by charcoal, 714
 improved by cold water, 498
 testing for sulphur, 255
 metal, definition of, 288
 varieties of, 289
 and wrought iron, difference, 725
 Piling, 837
 in Austria, 839
 iron, 848
 wood for charring, 214
 Pillars for roof, 77
 of furnace, 350
 Pilot Knob mines, 36, 42
 Pine tree, ashes of, 181
 Pinions for sheet iron, 792
 Pipe ore, 60
 Pipes, blast, 581
 Piston spring packing, 577
 Pitch of rock, 63
 Pit coal, 188
 Pits, 71
 Pittsburgh coke ovens, 232
 seam, 190
 Plan of a mine, 77
 of Wagner's rolling mill, 818
 Plate for top of stack, 352
 glass, iron for polishing, 91
 Platines, 795
 Platinum alloy, 129
 with steel, 936
 weldable, 85
 Plattner, appearances of iron, 92
 Player's blast oven, 516
 method of shingling by compres-
 sion, 808
 tuyere, 599
 Plumbago, 22
 crucible, 158
 Plymouth (Vt.) mines, 47
 Point of melting, 429
 Points for consideration in blast fur-
 naces, 629
 Poker for tuyere, 492
 Polaric ores, 38
 Polishing hoops, 779
 plate-glass, iron for, 91
 Portable hand shears, 833
 Port Henry furnace, 33
 Positions of furnaces, 608
 Potash, 426, 427
 as a flux, 440, 742
 bichromate of, assay, 169
 in wood ashes, 180
 Potash—
 permanganate of, assay, 170
 to prevent rust, 96
 with protosulphide of iron, 98
 Potassium alloy, 133
 Pot steel tyres, 922
 Pouillet, melting point of iron, 84
 Powders for refining, 692
 powder of iron, 81
 Practical directions for assaying, 168
 lessons from analysis of coal, 251
 remarks on charges, 478
 on furnaces, 362
 on ores, 58
 • Precautions before stopping the blast,
 611
 Prenat's distributor, 514
 Preparation of crucibles, 158
 of ores, care in, 390
 Preparatory workings, 71
 Present form of blowers, 562
 Pressure blowers, 567
 of blast, 482, 561, 566, 595
 Prevention of scaffolding, 610
 Price of chrome iron steel, 914
 of coal at pits, 203
 of digging coal, 196
 Primitive rocks, 63
 Principle deduced from analyses of cin-
 der, 734
 of gas furnace, 855
 Principles of chemistry of iron, 17
 of fluxes, 134
 Process, Ellershausen, 860, 865
 for analyzing ores, 136
 for puddled steel, 894
 of Bessemer, 868
 of Heaton for cast steel, 911
 of glossing Russia sheeting, 798
 of Heaton to introduce oxygen into
 iron, 912
 steel by direct, 861
 Uchatius, for steel, 897
 Processes for steel, 871, 872, 898
 Proling, experiments on iron, 82
 Proper mixture of ores, 424
 Proportion for charging, 462
 of lime for charges, 527
 Proportions at Acklam furnaces, 342
 at Cleveland, 449
 for burning lime, 153
 of fluxes, 142, 165
 Protecting puddling furnaces with
 water, 682
 Protection of sides of furnace, 682
 Protosulphide of iron, 97
 in the air, 103
 with lead, 98
 with potash, &c., 98
 with carbon, 98

- Protosulphide—
 with sesquioxide of iron, 98
 with sulphate, 98
 Protoxide of iron, 90
 carbonate of, 122
 and silica, 111
 Puddled balls, compression of, 762
 bars, average yield, 839
 iron for sheets, 791
 steel, tensile strength, 895
 Puddling ball rolls, 823
 bar, 664
 cinder, 733
 difficulties in, 688
 experiments in, 702
 from blast furnace iron, 689
 furnaces, 656
 construction of, 680
 double, 682
 protecting with water, 682
 furnace with water boshes, 676
 hook, 664
 improvements in, 675
 loss in, 718
 manipulations, care in, 715
 mechanical processes in, 684
 remarks on, 695
 steel, 893, 897
 theory of, 722
 with heated blast, 690
 with steam, 689
 Pure iron, 81, 734
 lime, 152
 ores, 418
 Purest iron, 851
 Purification of green vitriol, 102
 Purifying limestone, 147
 Purpose of a run-out fire, 720
 of a tuyere, 585
 Puzzolanas, 154
 Pyrites, iron, 100
 magnetic, 101
 with gold, 101
 Pyrolusite, 27
 Pyrometer for hot blast, 503
 Pyrometers, 521, 523
 Pyrometrical measurement, 493
 Pyrophoric iron, 89
 Pyroxene, 931

 Qualitative analysis of ore, 174
 Qualities of iron connected with cinder, 733
 of wrought iron, 750
 Quality affects color of sheet iron, 796
 of iron, when fixed, 745
 of metal depends on carbon, 396
 Quantitative analysis of ore, 933, 936
 Quartz flux, 155
 Quantity of air required for a blast, 369

 Quantity—
 of blast, 566, 628, 629
 of heat from fuel, 243
 of iron reheated, 826
 of ore to be used, 163
 Quarrying, 70
 Quartz, 24, 930

 Rabble, 664
 Rabbling steel, 895
 Rail pile, 837
 Railroad bars, weight of, 782
 for filling furnace, 385
 iron, 703, 706, 847
 rollers, 782
 Rails, cost of making, 840, 841
 rolling steel, 917
 sheet iron for, 795
 squaring ends of, 788
 steel capped, 919, 921
 straightening, 789
 trial of, 923
 Railway bars, 838
 Rain affecting blast furnaces, 632
 Rakes for drawing coal, 369
 Ralston, longest period of stopping the blast, 613
 Rammelsberg's analysis of Franklinite, 38
 Rapid roasting, 481
 Rationale of puddling steel, 895
 of steel breaking, 889
 Raw coal, benefit of, 254
 Reading anthracite furnace, 311
 Reasons why limestone is a good flux, 430
 Reaumur makes steel, 897
 Receivers of blast machines, 577
 Recent improvements in construction of puddling furnaces, 680
 Recording charges, 483
 Red clays, 39
 fossiliferous limestone ore, 55
 hematite, 31, 39
 hematites, charges for, 471
 limestone ore, 55
 ore, 39
 oxide, 39
 Reducing flame, 933
 Reduction of iron, 89, 274
 of ores, theory of, 405
 of silica by carbon, 109
 Reese's invention for rolls, 824
 Reeves' statement of material consumed, &c., 315
 Refined metal, yield from, 839
 Refinery cinder, 837
 Refining, 747
 by mixtures, 692
 iron, object of, 732

- Refining—
 methods of, 690, 721
 remarks on, 719
 theory of, 722
- Refractory cinder, 112
 nature of fluxes, 391
 ores, 372
 products, table of, 541
 stones, 533, 534, 535
- Regenerative gas furnace, 855
- Regenerators, 856
- Regnault on hydrogen and protosulphide of iron, 98
- Regular filling of a furnace, 383
- Regulating screws, Wilhelm's, 820
- Regulators of blast tuyeres, 577
- Reguli of crude iron, 141
- Reheating furnaces, 824
 and rolling, effects of, 915
- Relative amount of gases in a furnace, 404
 degree of fusibility of cinder, 425
 value of fuel, 243
- Remarks on analysis of coals, 249
 on anthracite, 200
 on ashes, 181
 on Bessemer metal, 916
 on blast machines, 597
 on charcoal forges, 693
 on charges, 478
 on charring wood, 220
 on coal, 189
 on construction of furnaces, 335
 on cylinder blast machines, 551
 on coking, 238
 on fuel, 201
 on furnaces, 362
 on making iron, 842
 on modern practice of roasting, 268
 on peat as a fuel, 184
 on puddling, 695
 on refining, 719
 on rolls and rolling, 815
 upon shingling, 813
- Remedy for scaffolding and dropping, 609
- Removal of carbon, 744
 of cinder, 401
 of impurities from iron, 732
 of silicon, 744
- Removing silex, 732
- Reniform ore, 41
- Result of analysis, how expressed, 938
- Results of bloom working, 651
 of combustion, 402
 of Lackawanna furnaces, 458
- Retorts, coking in, 238
- Reverberatory furnaces for roasting, 262
- Review of ores, 58, 257
 of shingling, 813
- Reviving of iron, 274
- Rhodium alloy, 129
- Rich lime, 152
 ores require more fuel, 421
- Richmond (Mass.) ores, 44
- Riddling ores, 265
- Riepe's process for puddled steel, 894
- Riley's steel, 871
- Ringgold, experiments for steel, 872
 process, 286
- Rivot, analysis of ores, 37
- Roast oven, 260, 261
- Roasted ores, cleaning of, 265
- Roasting, 481
 in air with wood, 269
 in heaps, 263
 in mounds, 262
 iron ore, 257
 ore, 259
 attention to, 370
 object of, 497
 ores, theory of, 267
- Rolled steels, 119
- Rollers, castings for, 786
 for railroad and heavy bar iron, 782
 for shape rails, 784
 for sheet iron, 792
 roughing, 765, 766
- Rolling, 753
 cold, 821
 guards, 778
 improvements in, 815
 mill, universal, 816
 merchant, 776
 tools in, 842
 steel rails, 917
- Rolls, consecutive series of, 816
 grooved chill, 822
 improvements in, 801
 mending cast iron, 821
 puddling ball, 823
 sweep grooved, 823
- Rochester Works, 473
- Rock and kidney carbonate ores, 55
- Rogers, analyses of ore, 433
 of ores, 934, 936
 moisture in air, 632
- Roman's method of charring wood, 216
- Roof, support of, 77
- Rooms for miners, 77
- Rosary, or chain trompe, 556
- Rose on magnetic pyrites, 101
 on protosulphide of iron, 97
 on quartz crystals, 85
- Rosin, to prevent rust, 96
- Rotary squeezer, 672, 763, 764
- Rouge, 91
- Roughing rollers, 765, 766
- Round water tuyere, 588

- Rowan's process of rolling, 922
 Rows, coking in, 229
 Roxbury (Conn.) mines, 47
 Royalty of Mr. Bessemer, 923
 Run-out fire, 652, 719, 747
 Russia furnaces, 363
 iron, 873
 sheeting, 798
 Rust of aluminum, 26
 of carbon, 19
 of iron, 19, 21, 95
 Rutile, 933
 alloy with, 128

 Salamander, 291
 furnace, 291
 Sal ammoniac mixture, 490
 Salisbury iron, 44
 Salt in refining, 741
 wells, boring, 69
 Samples, choosing, 164
 Sampling limestone, 480
 of ore, 479
 Sandage, 469
 Sand in iron, 728
 magnetic, iron from, 275
 Sandstone, 534
 artificial, 536
 Sand used in welding, 85
 Saucon Iron Works, 336, 506
 Saving of fuel in anthracite coke furnaces, 501
 Saw machine for rails, 788
 Saws, circular, for cutting iron, 835
 for cutting bolts, 836
 Scaffold cinder, 635
 Scaffolding, 36, 608, 609
 in the boshes, 313
 near the tuyere, 398
 Scale iron, 94
 Scales for iron works, 483
 Schafhäütl, spiegeleisen, 119
 compound, 714
 Schiff on hydrated sesquioxide of iron, 93
 Schlegel's puddled steel, 893
 Schneider hammer, 801
 Schuylkill coals, 208
 Schwarzkopf's blower, 565
 Science of blast furnace, 409
 Scorodite, 107
 Scotch tuyere, 593
 Scotland, black band ores, 50
 Scranton furnace, 320
 Scranton hot blast, 504
 Scraper, 66
 Scrap iron, 838
 Scraps for welding, 827
 Screening ores, 265
 Screw blast machine, 555, 558

 Screws, wrought iron, for housings, 820
 Screwing in the cutters, 836
 Seams of coal, 190
 Sea water on iron, 123
 Secondary rocks, 63
 Sediment from furnaces, 485
 Sefström's experiments, 116
 furnaces, 157
 Selection of ore beds, 60
 Self-fluxing ores, profitable, 418
 Senarmont on hydrated sesquioxide of iron, 93
 Series of rolls, 816
 Sesqui, 19
 Sesquioxide of iron, 19, 90
 hydrated, 92
 and lime, 93
 with protosulphide of iron, 98
 Sesquisulphide of iron, 100
 Setting the wood for charring, 211
 Shaft, 68
 Shafts, 74
 in coal mines, 193
 Shale for assaying, 161
 Shape of the tuyere, 591
 rails, rollers for, 784
 Shapes of furnaces, 320
 Shaw's gunpowder hammer, 807
 Shearing, 832
 cold, 836
 Shear, common force, 833
 moved by a crank, 834, 835
 moved by an eccentric, 833
 steel, 294, 878
 Shears, force, 832
 portable hand, 833
 Sheeting, Russia, 798
 Sheet tin, 127
 iron, 750, 791
 blooms for, 851
 charging boxes, 834
 color of, 796
 for nails, 795
 for stove pipes, 796
 heating oven for, 831
 manufacture, 850
 shears for trimming, 834
 Sheffield furnace, 873
 Shingling blooms, 756, 758
 by compression, 808
 review of, 813
 Shoeburyness, experiments on plates, 87
 Shoenberger & Co. on making malleable iron, 864
 Shovel, 65
 Shrubs, ashes of, 181
 Shurtliff ores, 472
 Siberia, natural magnets in, 38
 Siderum, 105
 Siegen, plan of roasting in, 270

- Siemen's furnace, 203
 pyrometer, 523
 regenerative gas furnace, 855
- Signs, 29
- Silesia furnace, 296
- Silex, 25, 930
 as a flux, 151
 as a foreign matter in ore, 497
 in iron, 724, 728
 in limestone, 147
- Silica, 24
 for assaying, 160
 from limestone, 148
 and protoxide of iron, 111
 reduced by carbon, 109
 spiegeleisen heated with, 122
 with protosulphide of iron, 99
- Silicate, 25
 of alumina, 26
 in coal, 209
 of protoxide of iron reduced by carbon, 111
- Silicates as fluxes, 426
 as solvents of metallic oxides, 428
 from limestone, 150
 with protosulphide of iron, 99
- Silicious carbonate of lime, 47
 ore, 44, 139, 414, 415
 assay of, 141
 best for gray iron, 397
- Silicic acid, 25
- Silicide, 25
- Silicon, 24, 109
 abstracted from cast iron, 122
 affinity for iron, 498
 removal of, 744
- Silver, arsenical iron taken for, 108
 alloy, 128
 coheres with gold, 85
 gray tinge to sheet iron, 800
- Simple test for iron ore, 174
- Sinking a shaft, 68
- Sinope, shot and shell, 109
- Siphon pipes, 506
- Site of a charcoal forge, 695
- Size of fuel, 388
 of ore, 389
- Sizes of furnaces and blasts, calculations upon, 620, 626
 of scaffolding and dropping, 609
- Slag, analysis by Aspelin, 907
 analysis of Cleveland, 449
 hammer, 647
 at Kirkless Hall, 450
- Slags, 22
 analyses of, 452, 453, 454, 909
 crystalline, 485
 estimation of, 934
 physical condition of, 475
- Slate coal, 190
- Sledge, 65
- Sliding valve, 594
- Slimy consistency of cinder, 746
- Slope in coal mine, 196
- Slopes, 75
- Slow roasting best, 268
- Small rod iron, 845
- Smelting of iron, 99
 ore, 275
 sulphurous materials, 444
- Smith's (G. H.) patent for steel, 872
 process, 281
- Smith (J. F.), on tensile strength of steel, 890
- Soapstone, 426, 535
 lining, when preferable, 703
- Soda as a flux, 426, 440, 742
 ferrate, 95
 nitrate of, 896
 to prevent rust, 96
 with protosulphide of iron, 98
- Soft charcoal, loss by, 501
 iron, 734
- Solvent of sesquioxide of iron, 91
- Solvents of titanium, 436
- South Carolina mines, 36
 Wales ores, 50
- Sow, the, 288
- Spalls, 350
- Sparks from iron, 90
- Sparry carbonate of iron, 60
 iron ore, 47
 ore, 31
- Spathic carbonate, 47
 ore, 31, 47
 ore furnace, 297
- Special process of blooming pig iron, 751
 properties of iron, 81
- Specific gravity of iron, 82
 of wood, 179
 of wootz, 883
 heat of iron, 84
- Spectroscope, 901
- Specular cast iron, 119
 iron, 90
 iron ore, 39, 60
- Speed of rolls, 815
- Spellen, 350
- Sphaerosiderite, 47
- Spiegeleisen, 35, 38, 119
 for Bessemer steel, 906
 for steel, 895
 heated with silica, 122
- Splint coal, 189, 190
- Sponge, metallic, 872
- Spongy cinders, 398
- Spontaneous ignition of iron, 89
- Squaring ends of rails, 788
- Squeezers, 761
- Stack, furnace, 357

- Stack, height of, 364
 Stahlberg mines, 47
 Stalactites, 145
 Stalagmites, 145
 Standardizing solutions, 102
 Standards for rolls, 815
 Starting the blast, 376
 Steam hammer, 757, 759
 hammer, Dudgeon's, 804
 hoist, 605
 jet cupolas, 570
 on protosulphide of iron, 97
 puddling with, 689
Stecken, 357
 Steel, 112, 870
 alloy with platinum, 936
 American uses of, 887
 analysis of, 900, 924
 Bessemer's, 898
 blistered, 873, 878
 boilers, 888, 892
 burnt, 88
 by arsenic, 109
 by direct process, 871
 by indirect process, 873
 capped rails, 919, 921
 carbon, 871
 cast, 879
 charcoal for, 877
 chrome iron, 913
 cranks, 893
 cutters, fastening, 836
 deprived of silicon, 751
 steel, determining carbon in, 927
 experiments with, 890
 for locomotives, 892
 from cast iron, 893
 from chromate of iron, 913
 from malleable iron, 885
 furnace for, 450, 873
 German metal for, 439
 Indian, 880
 -irons, ore for, 47
 Mushet's, 885, 915
 nitrogen in manufacture, 104
 of Black Diamond Works, 891
 of cementation, 873
 ore, 47
 patents for, 871, 872, 898, 899
 plates, test for, 88
 puddling, 893, 897
 rails, rolling, 917
 shear, 878
 and steely iron, 915
 tenacity of, 915
 tensile strength of, 889
 time required for, 877
 tyres, 921, 922
 Steely iron, 282
 tenacity of, 915
 Sterling (Mass.) iron, 47
 mines, 33
 ores, 471
 St Etienne double coke oven, 237
 Stengel on copper alloy, 125
 Sticking in the boshes, 313
 Stockbridge (Mass.) ores, 44
 Stodart on alloys, 129, 130
 Stonecoal furnaces, 310
 value of, 244
 Stone furnaces, 336
 Stoppage of coke furnaces, 614
 Stopper, use of, 380
 Stopping the blast, 610
 Storing charcoal, 370
 Stove-pipes, sheet iron for, 796
 Stoves, air heating, 488
 Straightening rails, 789
 Streak, 32
 Strength of cast iron, 932
 steel, 891
 of iron affected by phosphorus,
 105
 from mixtures, 465
 of tungsten alloy, 133
 Stripping for ore, 71
 Strike of rock, 63
 Stück oven, 291, 642
 Stückofen furnace, 277
 Sturtevant's blower, 563
 Styptic, tersulphate as, 103
 Styria, fuel in, 204
 gas furnace in, 860
 method of oxidizing, 264
 peat as a fuel, 226
 Styrian blauöfen, 628
 Substitute for the squeezer, 813
 Subterranean workings, 71
 Success, conditions of, 411
 Sugar bakery, steel boilers of, 892
 Sulphate of protoxide of iron, 101
 with protosulphide, 98
 Sulphates as oxidizers, 742
 of iron, 258
 Sulphide of gold, 97
 of nickel, 42
 Sulphides heated with carbon, 464
 of iron, 96
 roasted in the air, 103
 with protosulphide of iron, 99
 Sulphur, 22, 925
 absorbed by lime, 428
 evil influence of, 255
 in coal ashes, 187
 if ore detected, 172
 in ores, 174
 in slags, 99
 in the furnace, 442
 and iron, 96
 in iron containing carbon, 120

- Sulphur—
 testing pig iron for, 255
 Sulphurets of iron, 258
 Sulphuric acid, 23
 from pyrites, 101
 on cast iron, 123
 Sulphurous acid, 23
 fumes, 401
 materials, how best smelted, 444
 Superior iron, requisites for, 739
 Support of roof, 77
 Surface hardening, 109
 Suspension railroad for filling furnace, 385
 Sussex County, N. J., ores, 35
 Swallow-tail, 800
 Sweden, Bessemer steel in, 906
 case hardening iron, 109
 furnaces, 299, 363
 roasting ore in, 252
 Swedish bar iron, 115
 bellows, 544
 iron, 873
 Sweep grooved rolls, 823
 Sword blades, Damascus, 884
 Symbols, 29

 Table of accounts, 839
 of charcoals, 222
 of probable consumption of charcoal
 per 100 parts of crude iron, with
 ores of different sorts, 425
 of proportions of fluxes, 142
 Talcott on cost of erecting furnaces, 615
 Talc-slate, 535
 Tamping bar, 66
 Tangaree wood, 881
 Tap cinder, 111
 Tapping, 371, 382
 the gas from below the top, 532
 the iron, 393
 Tebo mine, 36
 Technical estimation of ores, &c., 934
 Telford on tenacity, 915
 Temperature, uniformity of, 521
 utility of high, 521
 Tempering Damascus steel, 884
 of metal, 750
 Tenacity affected by reheating and
 rolling, 915
 of iron, 84
 of tungsten alloy, 133
 of wrought iron and steel, 915
 Tenderness for hammering, 86
 Tennessee, black band, 51
 brown hematite, 46, 47
 fossil ores, 48
 peculiar ores, 57
 Tensile strength of cast steel boiler
 plates, 891

 Tensile strength—
 of chrome iron and steel, 714
 of iron, 84
 of Neuberg steel, 911
 of puddled steel, 895
 of steel, 889
 of titanized iron, 475
 Terne plate, 127
 Tersulphate of iron, 103
 Test, Eggertz's carbon, 904, 907
 for arsenic in iron, 108
 for green vitriol, 102
 for iron ore, 174
 for steel plate, 88
 Testing pig iron for sulphur, 258
 Tests for calcites, 930
 for hydraulic limes, 153
 of Neuberg steel, 911
 of steel, 890, 891
 at West Point Foundry, 914
 T hammer, 757, 758
 Theoretic metallurgy of iron, 17
 Theory of blast furnace, 402
 of fluxes, 134
 of hot blast, 494
 of reduction of ore, 405
 of refining and puddling, 722
 of roasting ores, 267
 Thickness of coal seams, 190
 Thomas' experiments, 198, 482
 use of gases, 520
 & Laurens' improvement in hot
 blast, 508
 Thomson, heat of iron, 84
 Throat of a furnace, 364
 Tilt-hammer, 753
 Timber for shafts, 75
 Timbering a drift, 73, 75
 of shafts, 75
 Time for charring in the woods, 224
 for tapping, 393
 required for roasting, 263
 for steel, 877
 Time to cut wood, 182
 Tin, alloy, 126
 promotes rust of iron, 96
 Titanic acid alloy, 128
 in iron, 128
 in ore, 436
 iron, 915
 sand, 38
 Titaniferous ores, 474
 Titanium, 485
 alloy, 127
 determining, 933
 in ore, 436
 Titanized iron, 475
 Tongs for rolling mill, 842
 Tools for mining, 65
 good ones required, 378

- Tools—
 in a rolling mill, 842
 of a blowery fire, 651
 of puddling furnace, 664
 Totten & Co.'s rolls, 822
 T rails, 783
 Transition rocks, 63
 Trial of rails, 923
 Tribasic phosphate of protoxide of iron, 106
 silicate of protoxide of iron, 111
 Trimming sheet iron, shears for, 834
Trompe, 277, 556
 Trout iron, 117
 Trundle valve, 594
 Truran on boiling and puddling furnaces, 682
 on hot and cold blast, 525
 objection to utilization of waste heat, 684
 on railway bars, 838
 on the modern squeezer, 814
 Tubs, double working wooden, 546
 Tubular oven, cast iron, 503
 Tungsten alloy, 133
 steel, 133
 Tunnel head of a furnace, 364
 Turf as fuel, 204
 charring, 224
 Turkish shot and shell, 109
 Tuyere, 641, 647
 holes, 356
 iron, care for, 379
 new form of, 599
 nose on, 379
 poker, 492
 stones, 356
 Tuyeres, 376, 585
 number of, 393, 482
 Tymp, 350
 Tympanum, 350
 Tyres, steel, 921, 922
- Uchatius process for steel, 897
 Ultramarine, preparation of, 97
 Ulverstone furnace, 629
 Unaccountable difficulties in blast furnaces, 633
 Uncoked coal, benefit of, 254
 Unfavorable indications of cinders, 398
 United States blast engines, largest, 200
 coal in, 202
 measurement of coal, 203
 steel rails in, 918
 Universal rolling mill, 816
 Unusual furnace deposits, 484
 Upsetting the blooms, 763
 U rails, 783
 Ure on mining, 62
 Use of saws in cutting bolts, 836
- Uses of steel, American, 887
 Using waste heat, 528, 529
 Utica, mines near, 42
 Utility of high temperature, 521
 Utilization of waste gas, 512, 516, 520
 of waste gases, 581
- Value of anthracite, 244
 of black band ore, 53
 of brown coal, 244
 of charcoal, 244
 of chrome iron steel, 914
 of coke, 244
 of fuel, 243
 of ore at Bloomsburg furnaces, 470
 of peat, 244
 charcoal, 244
 of stonecoal 244
 Valuing coal, 197
 Valves, 594
 Vanadium alloy, 134
 Vapor, decarbonization by, 898
 in atmosphere, 18
 Variation in density of coals, 204
 Variations in furnaces, 409, 410
 of weight in coal, 204
 Variegated cinders, 398
 Varieties of limestone and lime, 152
 of pig metal, 289
 Various chargings, 459
 forms of blast machines, 555
 Varvacite, 28
 Veins, 64
 of coal, 190
 how worked, 193
 of iron ore, 31
 Velocity of puddling rolls, 815
 Ventilation, 76
 Vertical blast engine, 576
 Vibration produces change in iron, 87
 Vienna sterro metal, 126
 View of a housing and section of rollers and foundation, 771
 of composition of anthracite coal of Pennsylvania, 207
 Virginia black band, 51
 bog ores, 56
 brown hematite, 46
 carbonates, 55
 fossil ores, 48
 peculiar ore, 57
 Viscid slag, 486
 Vitreous cinder best, 735
 Vitriol, green, 101
 Vivianite, 106
 with bog ore, 106
 Volatile matters in ores, 268
 Volcanoes, artificial, 97
 Volumetric assay, 169
 iron assay, solution for, 102

- Wages for digging ore, 80
 in coal working, 196
 Wagner's universal rolling mill, 816
 Wawayanda Lake mines, 35
 Wasseraufingen hot blast, 508
 Waste gas, 512, 516, 520
 gases, 487
 utilization of, 681
 heat, 487, 528, 529
 of finery fire, 721
 Water absorbed by charcoals, 223
 bosh, 680
 boshes, 676
 column machines, 557
 decomposed by iron, 96
 extraction of, 75
 for protecting puddling furnaces, 682
 hoists, 601
 in atmosphere, 18
 on protosulphide of iron, 97
 in wood, 178
 and iron, 95
 necessary for oxidation, 268
 pounds of, heated by coal, 248
 trouble from, 76
 tuyeres, 585, 587, 592
 tymp, 372
 Waterman and Beaver's rails, 921
 Weak blast injurious, 383
 Wedge, 65
 Weighing charges, 386, 387
 Weight of railroad bars, 782
 Weisse's and Ech's investigations, 632
 Weldability of platinum, 85
 Welding, 84
 heat to iron, 824
 iron, 703, 727
 steel, 844
 wrought iron scraps, 827
 Weldless steel tyres, 921
 Wells, boring salt, 69
 Welsh district, cost of rails, 842
 Westerman mill, 868
 Western States furnaces, 363
 works, 307
 Westphalia, black-band ores, 57
 West Point Foundry, chrome iron steel, 914
 Wet assay, 169, 171
 blast receiver, 578
 stock objectionable, 383
 White cast iron, 115, 123
 cinders, 398
 iron, 117
 a good forge iron, 397
 of small burden, 715
 produced by a cold furnace, 397
 pyrites, 100
 White—
 metal, 401
 does not ferment, 745
 for charcoal forge, 702
 how produced, 730
 with carbon, 729
 Wheel tires, rollers for, 782
 Widholm's bellows, 543
 Wilhelm's regulating screws, 820
 Williams' method for analysis, 937
 Wire iron, 703, 704, 706, 716, 846
 making, 781
 ropes for lifting coal, 196
 Wisconsin, brown hematite, 47
 mines, 37, 43
 Wöhler, cubes of iron, 88
 on titanium alloy, 128
 on iron in water, 96
 Wolfram steel, 133
 Wood, ashes of, 179, 718
 as a fuel, 178
 charring of, 209
 oven, 217, 218
 mound, 215
 -drying oven, 220
 effect on iron, 717
 hard and soft, 179
 hauling to hearth, 210
 specific gravity of, 179
 to an acre, 182
 water in, 178
 Wooden bellows of the common form, 543
 blast machine, 547
 cylinder bellows, 544
 tubs, double working, 546
 Woodward's jet cupola, 570
 Wootz, 130, 880
 analysis of, 882
 of India, 40
 specific gravity, 883
 Work-shaft, 75
 Working a charcoal furnace, 371
 coal veins with pillars and rooms, 194
 with post and stall, 194
 estimated by color of cinders, 398
 furnace for steel, 876
 in open air for ore, 70
 of coal veins, 193
 of ores, 420
 Works, erection of for making sheet
 irons, 852
 Wrought iron, 112, 725, 727, 750
 and cast iron, difference, 723
 and pig iron, difference, 725
 -iron screws for housings, 820
 iron, tenacity of, 915
 tuyeres, 585
 Wulf's oven, 291

- | | |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <p>Wurth, report on Ellershausen process, 865</p> <p>Yard, for coal and ore, 369</p> <p>Yates' process, 280</p> <p>Yellow iron pyrites, 100</p> <p>Yield of a furnace, 718</p> <p style="padding-left: 20px;">of coke, 241</p> <p style="padding-left: 20px;">from refined metal, 839</p> <p style="padding-left: 20px;">of metal, 476</p> <p style="padding-left: 20px;">of puddled bars, 839</p> | <p>Zaliski, peculiar ore, 58</p> <p>Zinc alloy, 126</p> <p style="padding-left: 20px;">and copper alloy, 126</p> <p style="padding-left: 20px;">crystallizes, 86</p> <p style="padding-left: 20px;">detected in ore, 176</p> <p style="padding-left: 20px;">in ore, 484, 485</p> <p style="padding-left: 20px;">to protect iron from rust, 96</p> <p style="padding-left: 20px;">with green vitriol, 101</p> <p>Zincing, 126</p> |
|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|

E R R A T A .

- Page 29, 15th line from top, for "unhydrated," read "anhydrated."
- " 41, 14th " " for "deep-blue," read "deep-blood."
- " 44, alter text after 1st line to—Fibrous limonite appears under beautiful forms known by the names *pipe ore*, *pot ore*, *shell ore*, &c. ; when reniform it often consists of alternate and concentric layers, &c.
- " 49, 4th line from top, for "and," read "and, sometimes," &c.
- " 55, 21st " " for "carbonitic," read "carbonated."
- " 56, 5th " " read "near, and southeast of, Helena," &c.
- " 326, We are under obligations to Mr. Jos. Hunt, superintendent of the new furnace at Yeagersville on the North Pa. R. R., for the carefully prepared outlines on pp. 325, 327, and 334.
- " 342, 1st line from top, for "Bolekön," read "Bolekow," &c.
- " 343, 11th " " for "and across," read "diameter across," &c.
- " 343, 13th " " read 2500 tons, the 5 being indistinct.

THE END.

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